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# Sinter Plant Windbox Recirculation and Gravel Bed Filter Demonstration. Phase 2 Construction, Operation, and Evaluation

National Steel Corp, Weirton, WV Weirton Steel Div

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# Sinter Plant Windbox Recirculation and Gravel Bed Filter Demonstration: Phase 2. Construction, Operation, and Evaluation

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16. ABSTRACT The report gives results of phase 2 of a program to demonstrate new technology for reducing exhaust gas volume and controlling emissions from the steel industry sintering process. Phase 1 (report EPA-600/2-75-014) entailed the engineering and design of a windbox gas recirculation system. Phase 2 entailed construction, operation, and evaluation of the system and, in addition, the construction, operation, and evaluation of a gravel bed filter system for particulate control. Windbox gas recirculation reduced particulates, hydrocarbons, SO2, and CO by an amount equal to the recycle rate (25% average). Capital and operatings costs (1978 dollars) were $5.3 million and $0.863 million, respectively. The gravel bed filter system achieved an average particulate removal rate of 84.5%. Capital and operating costs (1978 dollars) were $5.101 million and $1.197 million, respectively.

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Prepared for

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## PHASE II - FINAL REPORT ABSTRACT

This two-phase research program was initiated with the overall objective of developing new technology for the reduction of exhaust gas volume and the control of emissions from the sintering process in the steel industry. Phase I of the program entailed the engineering and design of a windbox gas recirculation system for the purpose of reducing effluent gas volume and related emissions from the National Steel Corporation, Weirton Steel Division No. 2 Sinter Machine located in Weirton, West Virginia. This effort was completed in fulfillment of Contract No. 68-02-1364. This Final Report was issued in August 1975 (available from NTIS as Report No. PB249-564/AS). Phase II of the program entailed the construction, operation and evaluation of the windbox gas recirculation system for the Weirton Steel Division No. 2 Sinter Machine. In addition, the Phase II Program called for the construction, operation and evaluation of a gravel bed filter system which heretofore had been untried technology in the control of sinter plant emissions.

This Final Report was submitted by the National Steel Corporation, Weirton Steel Division, as stipulated in Contract 68-02-1862 under the partial sponsorship of the Federal Environmental Protection Agency. This work was completed as of December, 1978.

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# SECTION I

## INTRODUCTION

Control of emissions from the main windbox system of sintering plants in the steel industry is a difficult problem. While technically feasible control processes exist, improvements to present technology are needed to achieve more effective, reliable and economical control of these emissions. Due to the high percentage of windbox particulate emissions under ten microns in size, cyclone and multiclone installations have been proven inadequate in this application. High moisture, acid salts and condensible hydrocarbons in the windbox discharge can cause serious operating problems in wet scrubber, electrostatic precipitator (dry and wet), and baghouse installations. Further disadvantages are associated with the wet-type control technologies due to the related water pollution control problems. Dry electrostatic precipitators have been the most common type of high efficiency collector used on windbox discharges. However, with the trend to higher basicity sinter, indications are that the dry electrostatic precipitator does not perform satisfactorily as a control technology in this application, in that the higher lime content of the sinter results in a dust with a resistivity which is not effectively collected. These problems have prompted efforts by National Steel Corporation, Weirton Steel Division, to investigate and develop new technology which may improve sinter plant emissions control.

Preliminary investigation by National Steel Corporation had indicated that recirculation of a portion of the gases generated in the windbox system of the sintering process may significantly reduce particulate and hydrocarbon emissions to the atmosphere. Further work completed by the Company, under the partial sponsorship of the Federal Environmental Protection Agency, developed the trade-offs of gas recycle ratio versus oxygen content, moisture content, and temperature of the gases above the bed, as well as power consumption and other important parameters (1) *. Preliminary investigation by the Company had also indicated, on a pilot scale, that gravel bed filtration can remove main windbox particulate emissions with the presence of condensible hydrocarbons in the gas stream. Based on these investigations, the technologies of windbox gas recirculation and gravel bed filtration were recommended for full scale evaluation.

* - See Section VI, References

The above work was considered Phase I of a two-phase research program jointly funded by National Steel Corporation-Weirton Steel Division and the Federal Environmental Protection Agency, for development of the new sinter plant windbox air pollution control technology. The Final Report for this Phase I program was issued in August 1975 (1). Phase II of the program, which followed the issuance of the Phase I Final Report, entailed the construction, operation and evaluation of the windbox gas recirculation system for the purpose of reducing effluent gas volume and related emissions from the National Steel Corporation, Weirton Steel Division No. 2 Sinter Machine located in Weirton, West Virginia. In addition, the Phase II program entailed the construction, operation and evaluation of a gravel bed filter system as the final particulate emission control device for the sinter machine.

The scope of work in the Phase II program required the issuance of this Final Report, detailing the results of this demonstration after the evaluations were completed.

## SECTION II - CONCLUSIONS

### A. Windbox Gas Recirculation System

1. The use of windbox recirculation at the Weirton Steel Division No. 2 Sinter Machine produced no significant change in the process control requirements and product quality.

2. Significant operating and maintenance problems noted during this demonstration were (1) fan erosion; (2) additional time required for routine maintenance of the sinter machine; and (3) expulsion of gases from under the sinter machine recycle hood during the use of higher than twenty-five percent recycle.

3. The percentage mass emissions reduction achieved for particulate matter is principally a function of the percentage of gas recirculated. Recirculation of twenty-five percent of the total waste gas volume was achieved.

4. The test program indicated that under either operating mode, more than 85 percent of the hydrocarbon charge rate was destroyed by the sintering process. However, in view of the questions concerning condensable hydrocarbon sampling and analyses procedures, and the inconsistencies in the data generated in the test program, it must be emphasized that any judgements concerning this parameter must be made cautiously.

5. The installation of the windbox gas recirculation system resulted in a decrease in coke breeze consumption of 146 joules per metric ton (125,000 b.t.u./ton) of sinter, an increase in electrical power consumption of 77 joules per metric ton (66,000 b.t.u./ton) of sinter, and a decrease in total energy consumption of 69 joules per metric ton (59,000 b.t.u./ton) of sinter. The trade-off between the decreased coke breeze consumption and increased electrical consumption represents an extremely unfavorable economic balance due to the relatively low cost of coke breeze and high cost of electricity.

6. The capital cost for the windbox gas recirculation system was $5,334,000 escalated to 1978 market conditions. The operating and maintenance cost, escalated to 1978 market conditions, was $864,000 per year which is equivalent to $0.79 per metric ton ($0.72/ton) of sinter produced.

SECTION II - CONCLUSIONS (cont'd)

B. Gravel Bed Filter System

1. Operating experience has established that moisture condensation occurs in the sinter machine exhaust system as a result of the waste gas passing through its dew point during the start-up phase of operation. This phenomemon cannot be totally eliminated and the detrimental effects of the moisture reaching the gravel bed filter system cannot be over-emphasized. The moisture combines with the lime-rich sinter dust collected in the beds to form a scale on the surface of the support screens. This blinding action, in turn, results in high backflush air velocity which can displace the media during the filter cleaning mode and cause short-circuiting and inefficiency in the system.

2. Test results during the demonstration period indicated a particulate removal efficiency of eighty-five percent for gravel bed filtration alone. These results were undoubtedly affected by the blinding problem cited above.

3. Testing indicated that gravel bed filtration reduced condensable hydrocarbon emissions by approximately twenty-eight percent. It is presumed that this reduction occurred due to condensation and deposition in the system at temperatures below 120° C. The benefit of this condition is questionable since it could be contributing to the screen blinding problem. Again it must be emphasized that due to the uncertainties involved in the method of condensable hydrocarbon determinations, data generated for this parameter should be viewed accordingly.

4. The operation of the revised gravel bed filter system will result in an increase in electrical power consumption of 46 joules per metric ton (40,000 b.t.u./ton) of sinter produced. Coke oven gas consumption will increase 47 joules per metric ton (41,000 b.t.u./ton) of sinter produced.

5. The projected capital cost for the revised gravel bed filter system is $5,101,000 based on 1978 market conditions. The operating cost, projected on 1978 market conditions is $1,198,000 per year which is equivalent to $1.10 per metric ton ($1.00/ton) of sinter produced.

C. Combined Systems

1. Windbox gas recirculation and gravel bed filtration are compatible control technologies.

2. An energy analyses of the combined systems indicate an increase in electrical power consumption of 86 percent or 123 joules per metric ton (106,000 b.t.u./ton), an increase in coke oven gas consumption of 21 percent or 47 joules per metric ton (41,000 b.t.u./ton) and a decrease in coke breeze consumption of 7 percent or 146 joules per metric ton (123,000 b.t.u./ton) of sinter produced. The total energy consumption will increase one percent or 24 joules per metric ton (21,000 b.t.u./ton) of sinter. It must, again, be emphasized that the trade-off between the decreased coke breeze consumption and the increased electrical power consumption presents an extremely unfavorable economic balance due to the relatively low cost of coke breeze and high cost of electricity.

3. The total projected capital cost for the combined systems is $10,435,000 based on 1978 market conditions. The projected operating cost of $2,062,000 per year of $1.89 per metric ton ($1.72/ton) of sinter produced.

## SECTION III - RECOMMENDATIONS

The relative merits of the Sinter Plant Windbox Gas Recirculation and Gravel Bed Filtration technologies cannot be established until total optimization of these facilities is achieved. For this reason, recommendations concerning the acceptability of these technologies cannot be documented. However, it is recommended that the economic, energy, and environmental relationships of the following considerations be thoroughly investigated by any entity contemplating the future application of these technologies in the sinter industry:

1. The size of the final air pollution control device can be minimized and the windbox gas recirculation rate can be maximized by reducing the leakage rate into the system at the pallet train and windbox junctures of the sinter machine.

2. A practicable method of minimizing the detrimental effects of moisture on the gravel bed filter system is necessary to improve the efficiency and reliability of the system.

In addition, it is recommended that any judgements concerning the condensable hydrocarbon data in this report be made cautiously. Considerable confusion presently exists nation-wide concerning the proper procedures for accurate condensable hydrocarbon sampling and analysis, and a standardized method should be developed and documented.

## SECTION IV

## DESCRIPTION OF SINTERING PROCESS AND AIR POLLUTION CONTROL TECHNOLOGY

### Section IVA - Description of Sintering Process

The sintering process is utilized by the steel industry to agglomerate large quantities of iron ore fines and steel mill waste iron oxides into a suitable raw material for the production of iron in a blast furnace. Figure No. 1 is a schematic flow diagram for a typical modern sinter plant. In essence a sintering plant is a solid waste recovery plant which conserves our natural resources and eliminates a solid waste disposal problem. The first step in the production of sinter involves the mixing of ore fines, thickener sludge, iron scale, and other iron-bearing waste materials with coke breeze and limestone to form a mass which can be ignited to produce an aggregate. The coke breeze is added to provide the required fuel for downdraft combustion in the sintering process, while the limestone provides the necessary flux for the sinter when it is subsequently processed in the blast furnace. These materials, which make up the burden to the sinter machine, are passed through a balling drum to blend and agglomerate the constitutents into a permeable mixture which will result in rapid and uniform sintering.

After balling, the mixture is charged onto a traveling grate (sintering machine) to form a bed approximately 30.5 centimeters (12 inches) deep. Sinter machines operated by National Steel Corporation range in size from 2.45 to 3.96 meters (8 to 13 feet) wide and 31.70 to 60.66 meters (104 to 199 feet) long. The No. 2 Sinter Machine at Weirton Steel Division is 3.66 meters (12 feet) wide and 44.81 meters (147 feet) long. Near the entry or feed end of the machine, the bed is ignited on the surface by gas burners in a furnace, and as the mixture moves along on the traveling grate, air is continuously drawn through the bed to support the combustion of the material. The combustion process progresses downward through the bed at temperatures of 1300° to 1500° C. (2372° to 2732° F.) until the entire depth of the charged material is sintered. The moving grate then discharges the sintered material for further processing and subsequent charging into the blast furnace.

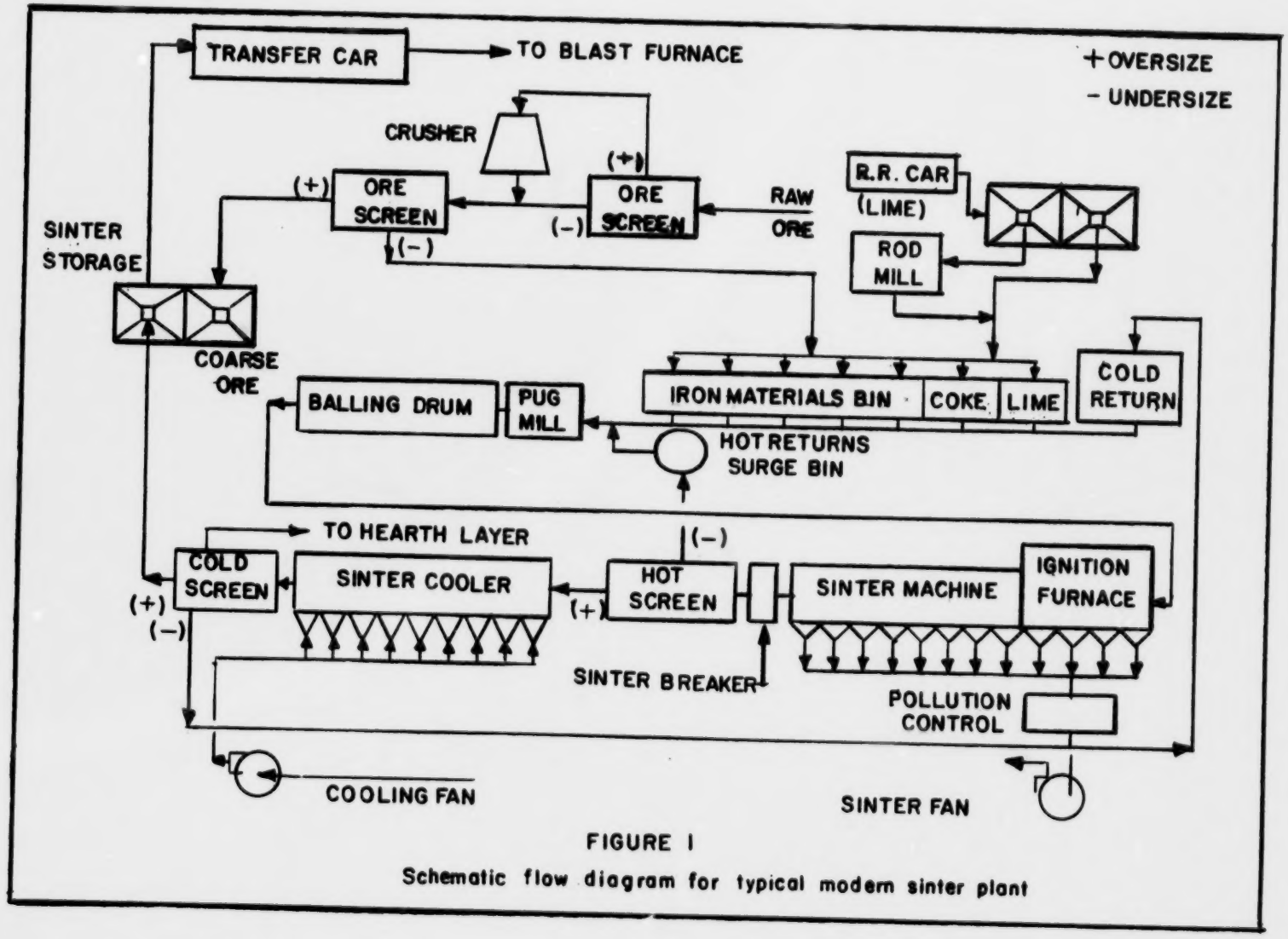



FIGURE I

Schematic flow diagram for typical modern sinter plant

Section IVA (contd)

Excess air plus the combustion products and unagglomerated particulate matter are drawn through the sintering bed and enter large chambers located under the moving grates. These chambers, which run the length of the machine are referred to as windboxes. A dual arrangement of fourteen windboxes is located under the Weirton Steel Division No. 2 Sinter Machine (see Figure 2). Each windbox is equipped with facilities to discharge and return to the plant, material which has been drawn through the grates and collected in the windboxes. Other components in the Weirton Steel Division No. 2 Windbox Gas System include pollution abatement facilities, induced draft fans, associated ductwork, and a main discharge stack. These facilities are discussed in detail in Sections IVB and IVC.

Section IVB - Description of Windbox Gas Recirculation System

Windbox gas recirculation, as applied to a sinter plant, involves the return of a portion of the windbox exhaust gas to a hood above the sinter bed. The objective is to reduce the volume of waste gas to be cleaned and to conserve a part of the sensible heat in the windbox exhaust gas. The portion of gas recycled to the machine must pass through the heat zone of the sinter bed thus providing the potential for the reduction of hydrocarbons through carbonization.

Figure No. 2 illustrates the general arrangement of the Weirton Steel Division Sinter Plant Gas Recirculation System. Two induced draft fans, identical in performance and construction, operate in parallel to provide the necessary air for downdraft combustion and cooling in the sinter bed. The effluent gases and particulate matter exhausted from the sinter bed by these fans enter the dual arrangement of fourteen windboxes under the sinter strand, and pass through downcomers to two parallel waste gas mains on the east and west sides of the machine. Each waste gas main transports fifty percent of the sinter machine windbox effluent to a series of four cyclone dust collectors for the removal of the larger particulate matter. From the cyclones, the windbox effluent re-combines in a plenum chamber for distribution to the two induced draft fans. Each fan was designed to exhaust 11,082 cubic meters per minute (393,000 ACFM) at a temperature of 194° C. (382° F.), and a static pressure of 1290 millimeters water column (50.8 In. WC) at a rating of 3357 kilowatts (4500 bhp).

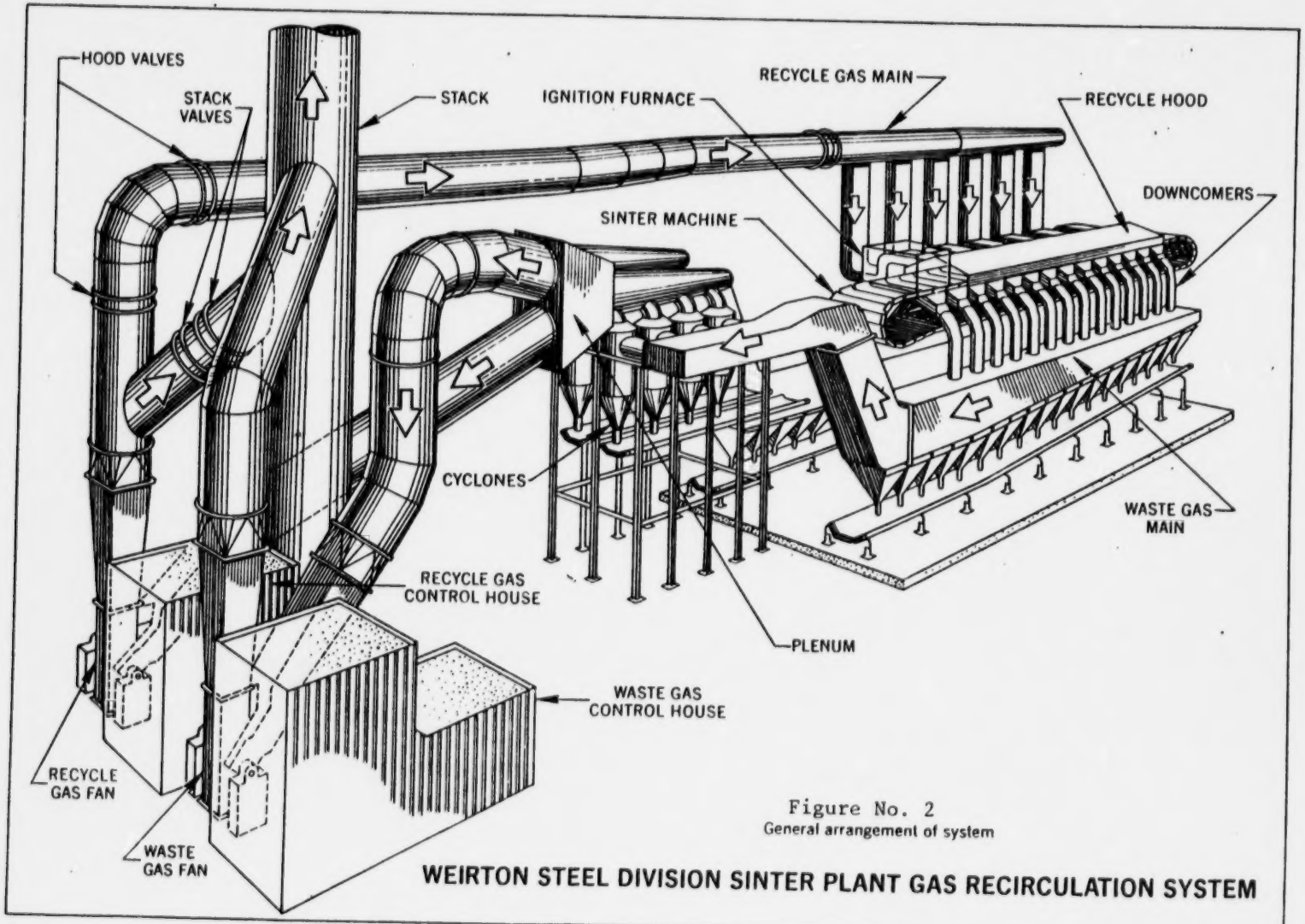



Figure No. 2
General arrangement of system

**WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM**

Section IV-B (cont'd)

The waste gas fan exhausts fifty percent of the total gas volume from the plenum chamber and delivers it to the stack or the gravel bed filter system. The recycle gas fan exhausts the remaining fifty percent of the gas volume from the plenum chamber, and recirculates, by design, 39 per cent of the total gas volume to the sinter machine via an insulated recycle gas main, six distribution ducts and a modular recycle hood which extends from the ignition furnace to the sinter breaker. The modular recycle hood is designed for quick removal of individual sections to facilitate maintenance. The remaining flow from the recycle fan is delivered to the stack or gravel bed filter system.

Two hood valves and two stack valves are located in the discharge ducts from the recycle gas fan. One hood valve in the recycle gas main, and one stack valve in the diverter duct on the recycle fan discharge, control the volume of gas recirculated to the sinter machine. The control circuits for the hood valve and the stack valve are so arranged that either valve can be selected to provide range control of the volume and pressure of gas recycled to the sinter machine hood while the other valve provides trim control. The selected range valve is manually positioned and the trim valve can be automatically controlled to maintain the desired hood pressure. In the automatic mode the controller senses hood pressure, and position in the selected valve in the duct to control the pressure in the hood. In addition, two manually operated valves, one each upstream of the previously discussed hood and stack valves. are normally used for shut-off of gas flow. These four valves provide flexibility in the system to permit a once-through operation, or recirculation rates ranging from zero to fifty percent.

A comprehensive evaluation of the advantages and disadvantages of Windbox Gas Recirculation was completed prior to committing the installation of this technology for the Weirton Steel Division No. 2 Sinter Machine. This technology offers the following potential advantages:

1. The quantity of gases to be cleaned by the final air pollution control facility is reduced by the percentage of waste gas recirculated.

2. The capital investment for the final air pollution control facility is reduced.

3. The recirculated portion of gas passes through the heat zone in the sinter bed, thus providing the potential for hydrocarbons reduction via carbonization.

4. The recirculation of hot gases to the sintering process provides a potential for energy conservation.

Potential disadvantages of this technology are as follows:

1. Higher maintenance requirements will result due to the installation of additional facilities. In particular, recycle hoods over the sinter machine limit accessibility for pallet maintenance, etc.

2. Downtime could result during the retrofit of this technology to the Sinter Plant.

3. A decrease in the oxygen content of the recirculated gas to the sinter bed could affect the production rate of the sinter machine, as well as sinter quality.

It was concluded that the advantages of this technology outweighed the disadvantages, and the system was designed to reduce the effects of the unfavorable factors cited above. Special consideration was given to the minimization of disadvantages Nos. 2 and 3. This effort significantly influenced the design of the system in that it was determined that this facility should provide for recirculation of a percentage of the gases from all windboxes to a recycle hood over the entire length of the machine (total windbox recirculation) as opposed to the recirculation of a percentage of the gases from the first several windboxes to a recycle hood over the remaining last several windboxes (front to rear recirculation). Front to rear recirculation offered the advantage of better accessibility to the machine, as well as the potential of a higher efficiency in hydrocarbon reduction through carbonization. However, total windbox recirculation was more adaptable to sinter machine retrofit and, in addition, this mode provides for the maximum oxygen content in the recirculation gas. Based on these considerations, it was concluded that recirculation over the entire length of the machine should be employed and design calculations concluded that a 39 percent recycle could be achieved without rapidly decreasing the oxygen content in the recirculated gas.(1)

## Section IVC - Description of Gravel Bed Filter System

Prior to 957, the gas cleaning applications of gravel bed filtration on an industrial scale were developed in the direction of intermittent type equipment operation, and the range of potential methods involving continuous gas cleaning was neglected. One of the first examples of gravel bed filtration was a system applied to the effluent from a carbide furnace in a German chemical plant. Here, the dusty waste gases from the carbide furnace were pre-cleaned in cyclones and then cleaned of fines in a bed of granular coke, that was also the feed material. When the coke bed became saturated with dust, the bed was replaced and the dust saturated coke was fed into the furnace.

In 1957, Max and Wolfgang Berz, in Germany, succeeded in devising a system which permitted a continuous, fully automated cleaning of the filter bed from the dust load within the collector. This technology utilized a horizontally arranged filter bed, consisting of uniform quartz grains housed in a flex-spring support casing. To clean the filter bed, the casing was virbrated by means of an eccentric motor. This moved the gravel grains in an elliptical motion within the bed. This motion separated the dust and moved it down into a dust collecting chamber. Thus the granular bed was used for the first time for continuous separation of dust from effluent gases on an industrial scale. Since that time variations in this design were developed and utilized as air pollution control devices in the cement and lime industries. However, the application of gravel bed filtration technology at a sinter plant did not occur until 1976 when a full scale system was commissioned at Weirton Steel Division of National Steel Corporation.

The gravel bed filter system installed on the No. 2 Sinter Machine at Weirton Steel Division is a special unit specifically designed for sinter plant application. The system consists of a parallel arrangement of 24 filter modules of equal size (see Figure No. 3). The filter modules are assembled into groups of four and are stacked vertically to utilize space more efficiently. There are two such vertically stacked towers, each containing twelve modules.

The modules are cylindrically shaped and contain an upper and lower filter bed. Each bed includes a horizontal grid and screen which supports 0.62 cubic meters (22 cubic feet) of garnet or steel grit filter media at a depth of 90 to 100 millimeters (3.5 to 4 inches). Various sizes of filter media can be used, but a range from 2 to 4 millimeters (0.08 to 0.16 inches) has given satisfactory results.

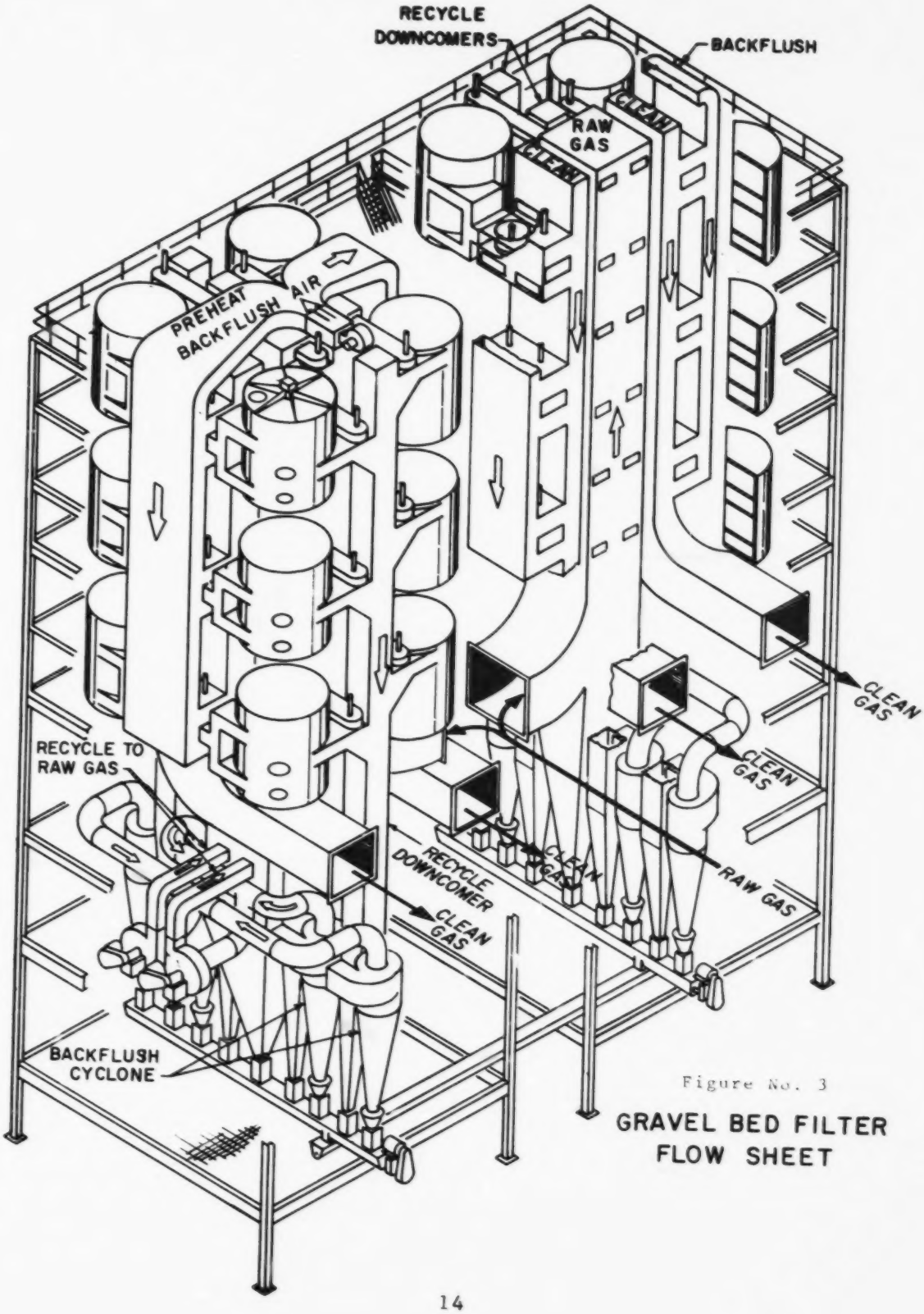



Figure No. 3

GRAVEL BED FILTER
FLOW SHEET

Section IVC - Description of Gravel Bed Filter System (contd)

The operation of each filter module is identical; 22 modules are in the forward flow cleaning mode of collecting and filtering sinter dust onto the minute surfaces of the media while two modules (one in each tower) are isolated in a backflushing mode for removal of the collected dust from the filter beds. The system is designed to accept dust laden gas at a flux rate of 0.61 cubic meters of gas per second per square meter of bed area (120 cubic feet of gas per minute per square foot of bed area) with a flange-to-flange pressure drop of approximately 330 millimeters of water column (13 inches of water column).

During the backflush mode, a revolving rake agitates the filter media while a reverse flow of air flushes the fine dust particles to a common downcomer duct and a screw conveyor for recovery.

A detailed description of the sequence of operation follows below.

Raw dust-laden gas leaving the windbox passes through the pre-cleaning cyclones and induced draft fans, then enters the interior raw gas duct of the gravel bed filter driven by its own induced draft fan (see Figure No. 3).

The raw gas (see Figure No. 4) enters from the raw gas duct (1 ) into the upper or raw gas chamber (14). The gas flow passes down through the filter media (6) where the entrained dust is captured. The gas passes through the media support screen (7), into the clean gas chamber (12), out the clean air branch (8), and into the clean air duct (9). Note that this flow path is determined by having the raw gas/recycle valve plates (3) and the backwash/clean air valve plate (10) in the down position. The cleaned gas then exits through the I.D. fan to the stack not shown (Figure No. 3).

The above "forward flow" or "cleaning mode" continues until the automatic cycle timer in the main control panel calls upon that module to enter the "backflush mode" of operation (refer to Figure No. 5).

At this time, the valve operator (16) lifts the backflush/clean air valve plate (10) into the backflush position, isolating the module from the I.D. fan suction and exposing it to the backflush (preheated ambient) air. The valve actuator (2) then lifts the raw gas/recycle valve plate (3) into the backflush position isolating the module from the raw gas dust (1) and exposing it to the recycle downcomer (13)

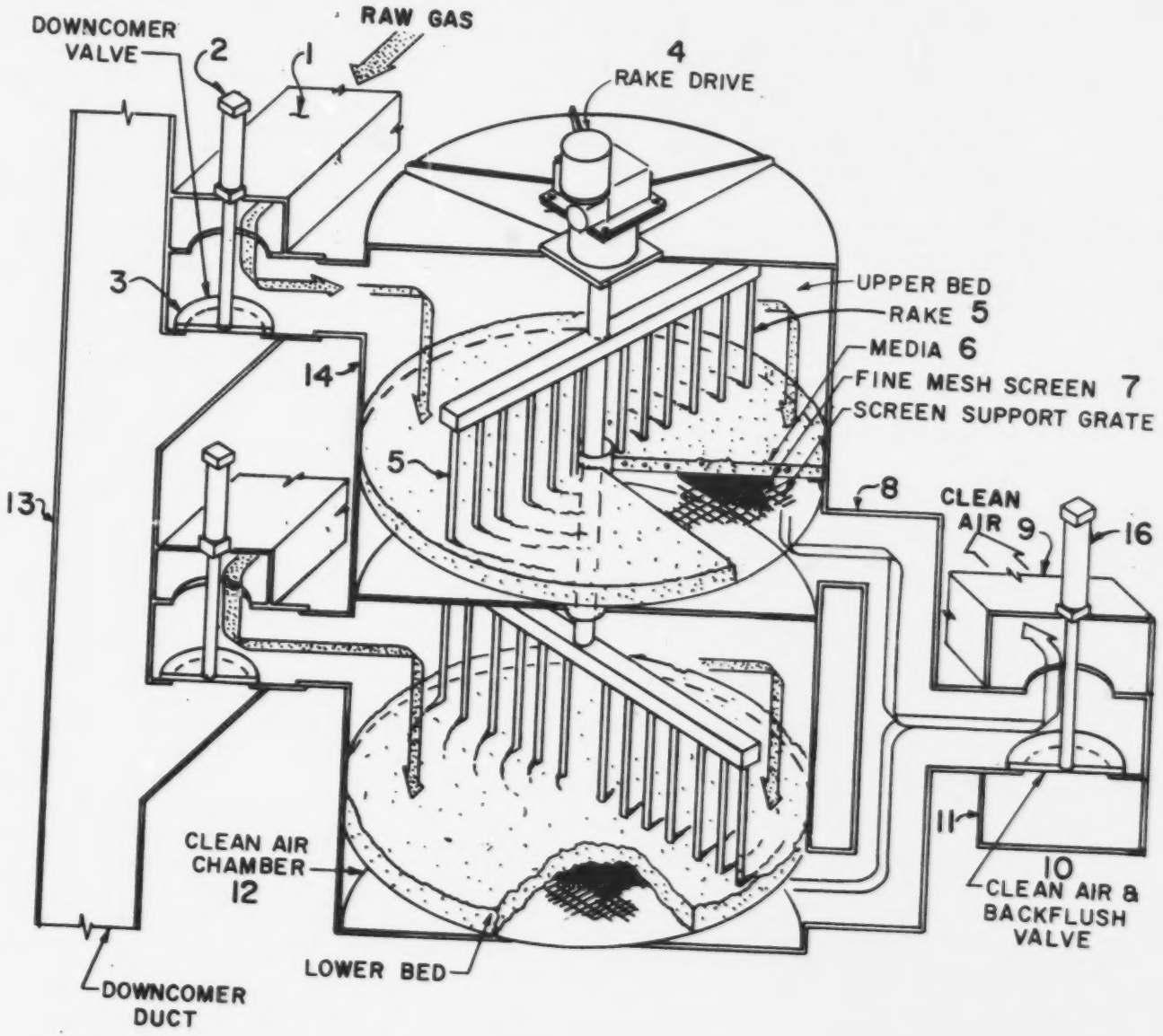



Figure No. 4

**FILTER MODULE**
**FORWARD FLOW MODE**

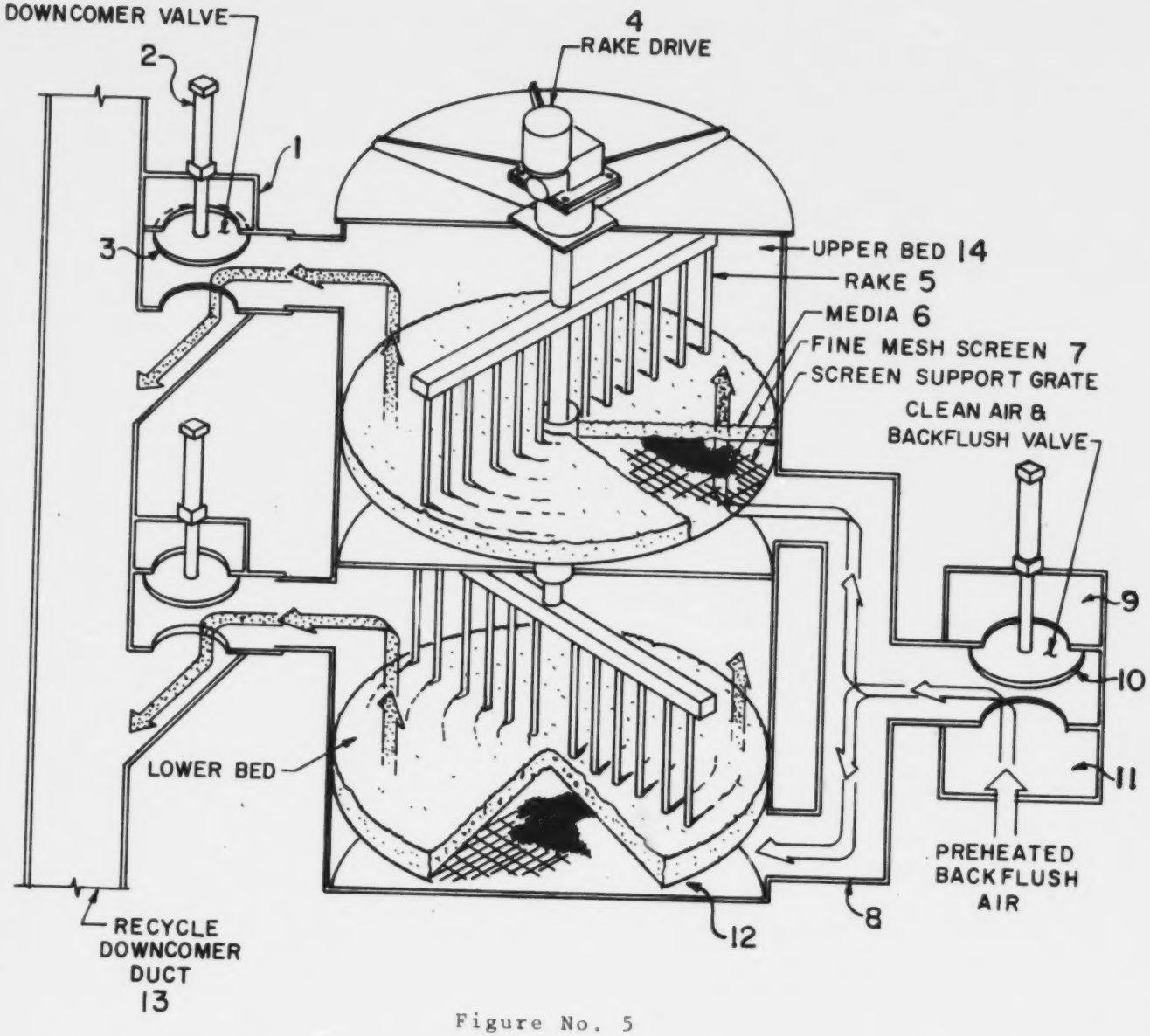



Figure No. 5

**FILTER MODULE BACKFLUSH MODE**

Section IVC - Description of Gravel Bed Filter System (contd)

Backflush air flows into the module through the backflush duct (11) and upward through the bed (6). The backflush air is externally pre-heated by coke oven gas-fired burners in order to maintain a backflush temperature of 149° C. (300° F.). The rake motor/reducer (4) turns the rake (5) and begins agitation of the bed, which dislodges the agglomerated dust and allows it to flow out of the upper chamber (14) and into the recycle downcomer (13). This recycle gas is then passed through a settling chamber and cyclones before it is introduced into the raw gas duct to be added to the incoming process gas. The backflush cyclones are small diameter high efficiency units motivated by induced draft backflush fans.

After the pre-set backflush time interval has elapsed, both valves (3 and 10) again move and place the module back in the forward flow or "cleaning mode" position of normal operation.

# SECTION V

# EVALUATION OF THE WINDBOX GAS RECIRCULATION AND GRAVEL BED FILTER SYSTEMS

## Section V-A - Effects on Sintering Process and Product Quality

### Introduction

The installation of a gravel bed filter system as the final air pollution control device on a sinter machine should not have significant effects on the sintering process and/or product quality. However, the installation of a windbox gas recirculation system could have serious effects in these regards since this technology becomes an integrated part of the sintering process.

In order to determine any significant differences in the operating parameters and product quality derived from the utilization of windbox gas recirculation, tests were conducted under both conventional operation (a no-recycle base period of eight days), and maximum permissible waste gas recirculation to the sinter strand (a recycle period of seven days). The parameters measured during the base and recycle periods included sinter mix composition, strand speed, fan characteristics, energy requirements, gas volume, temperature, pressure and composition data, product composition, production rate and downtime. Sufficient data were obtained for certain parameters to permit a statistical analysis and establish the standard deviation ($\sigma$). The $2\sigma$ value is used in certain tables of this section to establish variability of the data, and as an estimate of process stability, where applicable.

This portion of the program did not include the determination of particulate, condensable hydrocarbon, and sulfur dioxide loadings in the gas system. It had been determined in the early planning stages of this project that environmental testing would be deferred until after the operational and product quality aspects of the system had been established.

## Test Procedure

All operating data were logged hourly during daylight turn for each day comprising the respective test period. Gas temperature in Windbox Nos. 3, 5, 7, 9, 13 and 14 and the main temperature were obtained from sinter plant temperature recorders for both east and west windboxes. Gas pressures in Windbox Nos. 1, 5, 9, 11, 13 and 14 and the fan inlet and main pressure were obtained from manometers or recording charts located in the plant for both east and west sides. Also recorded were data obtained from various charts, meters and gauges for waste and recycle gas fan current and draft pressure readings, hood pressures for hoods 1 through 4, plenum pressure and temperature, strand speed, cooler speed, coke oven gas flow, drum and pug mill moistures and mix temperature. At certain times readings were delayed or missed due to sinter plant delays. Visual observations of the sinter plant were also made to ascertain the general operating conditions of the system.

Sinter was sampled for screen and tumble tests for each day of the test periods. Sinter samples were obtained at hourly intervals, with samples being composited to obtain four samples composed of an 8:30 - 9:30 A.M. composite, a 10:30 - 11:30 A.M. composite, a 12:30 - 1:30 P.M. composite and a 2:30 - 3:30 P.M. composite. Each sample consisted of three cuts made across the width of the product conveyor belt with a shovel, care being taken to obtain a representative sample. Two concurrent samples were placed into a five-gallon can to form a composite sample for a two-hour period which contained 50 to 60 pounds of sample. Standard ASTM screen and tumble tests for sinter were performed upon the composite sample. A small sinter sample was also taken on hourly intervals and composited for the turn for later chemical analyses. As was the case with recording of sinter plant operating parameters, certain sinter samples for physical testing and chemistry were either delayed or cancelled if sinter plant operating conditions dictated this action.

A sample of the sinter feed mixture as it was placed upon the strand was obtained twice a day at approximately 10:00 A.M. and 1:00 P.M. for moisture determination. The moisture determination was performed immediately through use of a "Moisture Teller" where 100 grams of the material are dried for 15 minutes under a stream of hot air. This procedure is adequate to provide accurate moisture measurements for sinter feed mixture.

Other operating data such as sinter mix composition, sinter plant production and downtime were obtained from sinter plant operation data sheets.

## Sinter Strand Operation - Test Results and Discussions

The sinter mix composition for both the base and recycle periods was similar as indicated in Table No. 1. Only the sinter fines content differed by an appreciable amount, and this may not be statistically significant in terms of the $\pm 2\sigma$ variability associated with the two mean values. Total fluxstone (dolomite and calcite) input which was slightly lower during the recycle period is reflected in the slightly lower basicity for the sinter that was produced. On the whole, the sinter mix composition was more variable during the base period. A difference in sinter mix composition should not be a factor influencing any differences in sinter plant operation or sinter quality.

The plant operating data presented in Table No. 2 exhibit good consistency between the two periods. Sinter strand speed was identical, although somewhat more variable during the recycle period. The lower ignition gas consumption rate during the recycle period was principally attributed to the rebuild of the ignition furnace during the maintenance shutdown between the base and recycle periods. After improved operation of the system was subsequently achieved, it was discovered that in the recycle mode, lower heat input to the sinter machine via coke breeze was required as a result of the heat content in the recirculated gas stream (see Section VI-D).

The sinter mix moisture was not significantly different between the two periods. During the recycle period more water was added in the pug mill and less in the balling drum. There is no indication that the use of waste gas recycle altered the mix moisture requirement for proper strand operation.

TABLE 1.

SINTER MIX COMPOSITION (WT. %)

| Material | BASE PERIOD Mean | BASE PERIOD ±2σ | RECYCLE PERIOD Mean | RECYCLE PERIOD ±2σ |
|---|---|---|---|---|
| Coke Breeze | 6.69 | 0.55 | 6.54 | 0.75 |
| Ore "A" | 24.48 | 6.49 | 23.44 | 1.49 |
| Ore "B" | 21.14 | 4.54 | 20.15 | 1.25 |
| Ore "C" | 10.65 | 0.54 | 10.98 | 0.70 |
| Roll Scale | 5.05 | - | 5.19 | - |
| Flue Dust | - | - | - | - |
| Sinter Fines | 6.38 | 4.35 | 8.85 | 5.42 |
| Dolomite | 11.26 | 2.45 | 10.95 | 0.77 |
| Calcite | 14.33 | 2.47 | 13.90 | 0.85 |

NOTE: - Data do not include hot returns and sludge which are not metered into mix at pre-determined rate.

TABLE 2.

OPERATING DATA

| Item | BASE PERIOD Mean | BASE PERIOD ± 2σ | RECYCLE PERIOD Mean | RECYCLE PERIOD ±2σ |
|---|---|---|---|---|
| Strand Speed | | | | |
| Meters per Second | 0.0472 | 0.0041 | 0.0472 | 0.0061 |
| (Feet per Minute) | (9.3) | (0.8) | (9.3) | (1.2) |
| Cooler Speed | | | | |
| Meters per Second | 0.0386 | 0.0015 | 0.0376 | 0.0041 |
| (Feet per Minute) | (7.6) | (0.3) | (7.4) | (0.8) |
| Ignition Gas | | | | |
| Cubic Meters per Second | 0.4752 | 0.0603 | 0.4212 | 0.0496 |
| (Cubic Feet per Hour) | (60,408) | (7,668) | (53,543) | (6,310) |
| Mix Moisture | | | | |
| Percent | 6.9 | 1.9 | 6.6 | 1.1 |
| Waste Gas Fan Current | | | | |
| (Amps) | 342 | 13 | 339 | 37 |
| Recycle Gas Fan Current | | | | |
| (Amps) | 325 | 22 | 340 | 21 |
| Production | | | | |
| Metric Tons per Day | 4,668 | 234 | 4,583 | 1,138 |
| (Short Tons per Day) | (5,142) | (258) | (5,049) | (1,254) |
| Delays | | | | |
| Hours per Day | 0.71 | - | 1.12 | - |

Sinter Strand Operation - Test Results and Discussion (contd)

Actual sinter production was lower and more variable during the recycle period. When production is corrected to a delay-free basis, both periods averaged 1947 metric tons per eight-hour shift. The average 12.2 minute per shift delay time for the base period was comprised of several short delay periods. In contrast, the 22.5 minute per shift average delay during recycle is from a single outage of 135 minutes. Thus, the continuity of operation was better during the recycle period.

Bed suction was higher during the recycle period than during the base period. As indicated in Table No. 3 and Figure No. 6 this difference was about 15.3 centimeters of water (6 inches of water) over most of the strand. A portion of the increase could be attributed to repair of leaks during the maintenance outage between test periods. However, the major portion should be attributed to the recycle of waste gas. This may have included a greater bed depth which could not be accurately determined. Variability in bed suction was generally less during the recycle period. Under normal operation an increase in bed suction is associated with a less permeable bed which restricts air flow and reduces production rate. Total waste gas flow, as measured at the plenum, was slightly lower during the recycle period.

The windbox suction profiles shown in Figure No. 6 are typical for the process. Other than the difference in absolute suction, the profiles are similar and would not suggest a fundamental difference in the process associated with recycling.

The sinter machine waste gas did not differ significantly in temperature between the two periods as measured at the individual windboxes. The strand waste gas system is divided along the strand length with the halves identified as east and west side. Data in Table No. 4 were obtained from the normal waste gas temperature instrumentation. These data and Figure No. 7 indicate a somewhat higher waste gas temperature for the east side through windbox ten during the base period.

TABLE 3.

WINDBOX SUCTION DATA

| Location | BASE PERIOD Mean Millimeters W.C.** | BASE PERIOD Mean Inches W.C. | BASE PERIOD ±2σ Millimeters W.C. | BASE PERIOD ±2σ Inches W.C. | RECYCLE PERIOD Mean Millimeters W.C. | RECYCLE PERIOD Mean Inches W.C. | RECYCLE PERIOD ±2σ Millimeters W.C. | RECYCLE PERIOD ±2σ Inches W.C. |
|---|---|---|---|---|---|---|---|---|
| Windboxes | | | | | | | | |
| 1W | - | - | - | - | - | - | - | - |
| 5W | 418.8 | (16.49) | 76.5 | ( 3.01) | 723.6 | (28.49) | 457.2 | (18.00) |
| 9W | 726.4 | (28.60) | 205.5 | ( 8.09) | 809.5 | (31.87) | 309.6 | (12.19) |
| 11W | 761.5 | (29.98) | 136.1 | ( 5.36) | 903.5 | (35.57 | 103.9 | ( 4.09) |
| 13W | 742.4 | (29.23) | 140.0 | ( 5.51) | 894.1 | (35.20) | 102.6 | ( 4.04) |
| 14W | 571.8 | (22.51) | 253.2 | ( 9.99) | 728.2 | (28.67) | 138.7 | ( 5.49) |
| 1E | 791.2 | (31.15) | 122.7 | ( 4.83) | 859.3 | (33.83) | 206.0 | ( 8.11) |
| 5E | 748.8 | (29.44) | 296.9 | (11.69) | 883.4 | (34.78) | 132.3 | ( 5.21) |
| 9E | 804.2 | (31.66) | 125.7 | ( 4.95) | - | - | - | - |
| 11E | 756.7 | (29.79) | 126.7 | ( 4.99) | 887.0 | (34.92) | 100.1 | ( 3.94) |
| 13E | - | - | - | - | - | - | - | - |
| 14E | 1042.4 | (41.04) | 351.3 | (13.83) | 1182.9 | (46.57) | 244.6 | ( 9.63) |
| Waste Fan | 1222.0 | (48.11) | 100.8 | ( 3.97) | 1395.2 | (54.93 | 223.3 | ( 8.79) |
| Recycle Fan | 1229.1 | (48.39) | 98.0 | ( 3.86) | 1342.4 | (52.85) | 71.1 | ( 2.80) |
| Plenum | 1174.0 | (46.22) | 99.6 | ( 3.92) | 1279.7 | (50.38) | 77.5 | ( 3.05) |
| Hood* | | | | | | | | |
| #1 | 2.62 | ( 0.103) | 0.78 | ( 0.78) | 6.20 | ( 0.244) | 2.90 | ( 0.114) |
| #2 | -1.37 | (-0.054) | - | - | 0.81 | (-0.032) | - | - |
| #3 | -0.05 | (-0.002) | - | - | 4.06 | ( 0.160) | 2.82 | ( 0.111) |
| #4 | 2.84 | ( 0.112) | 1.40 | ( 0.055) | 6.48 | ( 0.255) | 2.82 | ( 0.111) |
| Integrated | 1.93 | ( 0.076) | 0.58 | ( 0.023) | 4.98 | ( 0.196) | 2.18 | ( 0.086) |

* - Negative value means positive pressure under hood

** - W.C. means Water Column

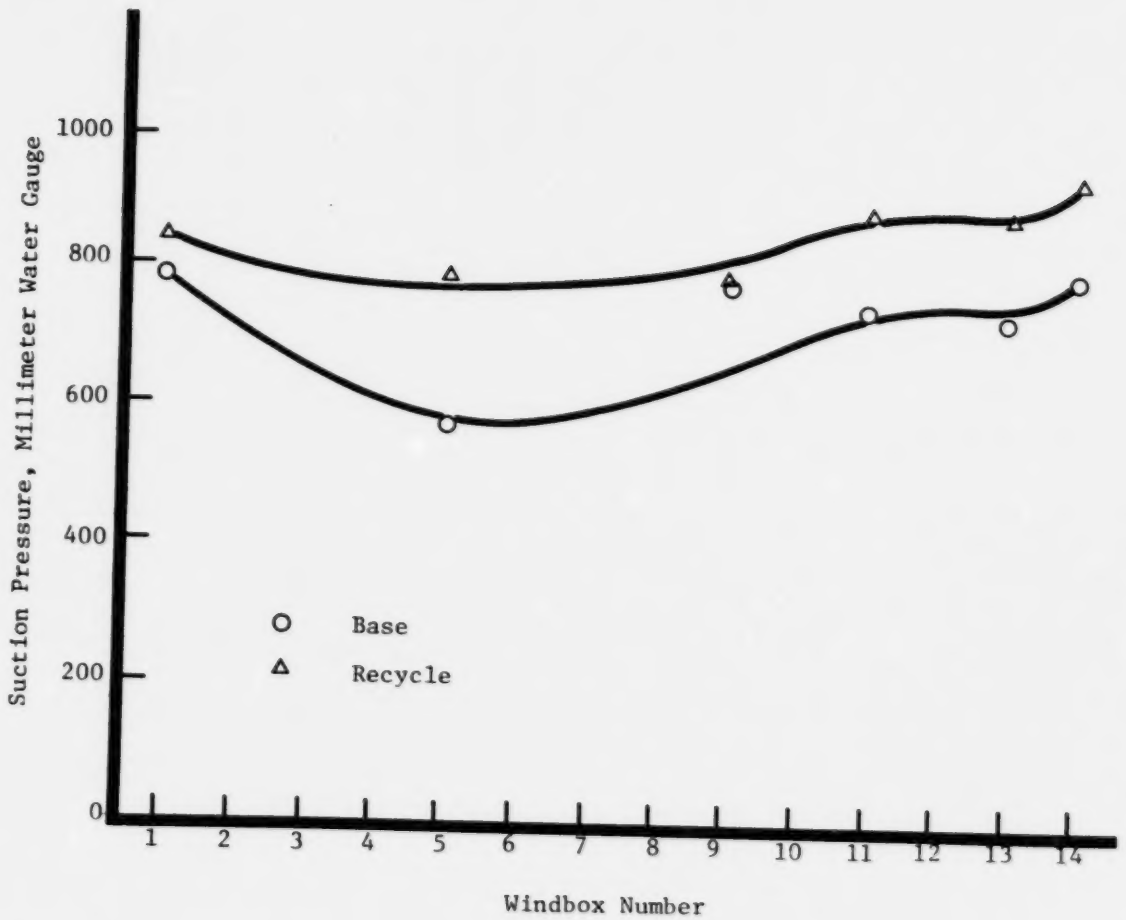



FIGURE 6 COMPARATIVE AVERAGE STRAND SUCTION PROFILES

TABLE NO. 4

TEMPERATURE DATA

| Location | BASE PERIOD Mean °C. | (°F.) | BASE PERIOD ± 2σ °C. | (°F.) | RECYCLE PERIOD Mean °C. | (°F.) | RECYCLE PERIOD ± 2σ °C. | (°F.) |
|---|---|---|---|---|---|---|---|---|
| Windboxes | | | | | | | | |
| 3W | 89.4 | (193) | 38.9 | ( 70) | 88.3 | (191) | 18.3 | ( 33) |
| 5W | 85.6 | (186) | 11.1 | ( 20) | 90 | (194) | 33.3 | ( 60) |
| 7W | 98.9 | (210) | 48.9 | ( 88) | 102.8 | (217) | 35.6 | ( 64) |
| 9W | 126.1 | (259) | 39.4 | ( 71) | 131.1 | (268) | 30 | ( 54) |
| 11W | 175.6 | (348) | 80.6 | (145) | 154.4 | (310) | 56.7 | (102) |
| 13W | 281.1 | (538) | 121.1 | (218) | 269.4 | (517) | 106 | (191) |
| 14W | 226.7 | (440) | 75 | (135) | 240 | (464) | 95 | (171) |
| Main | 116.1 | (241) | 53.9 | ( 97) | 120.6 | (249) | 30.6 | ( 55) |
| 3E | 95 | (203) | 30.6 | 55) | 98.3 | (209) | 27.2 | ( 49) |
| 5E | 95.6 | (204) | 47.8 | ( 86) | 95 | (203) | 18.3 | ( 33) |
| 7E | 125.0 | (257) | 40.6 | ( 73) | 120.6 | (249) | 43.3 | ( 78) |
| 9E | 119.4 | (247) | 101.1 | (182) | - | - | - | - |
| 11E | 219.4 | (427) | 110 | (198) | 218.3 | (425) | 109.4 | (197) |
| 13E | 218.9 | (426) | 68.9 | (124) | 265.0 | (509) | 146.1 | (263) |
| 14E | 202.2 | (396) | 88.3 | (159) | 236.1 | (457) | 170.6 | (307) |
| Main | 122.2 | (252) | 23.3 | ( 42) | 120.6 | (249) | 30.6 | ( 55) |
| Sinter Mix | 43.3 | (110) | 13.9 | ( 25) | 44.4 | (112) | 13.3 | ( 24) |
| Plenum | - | - | - | - | 117.2 | (243) | 26.1 | ( 47) |

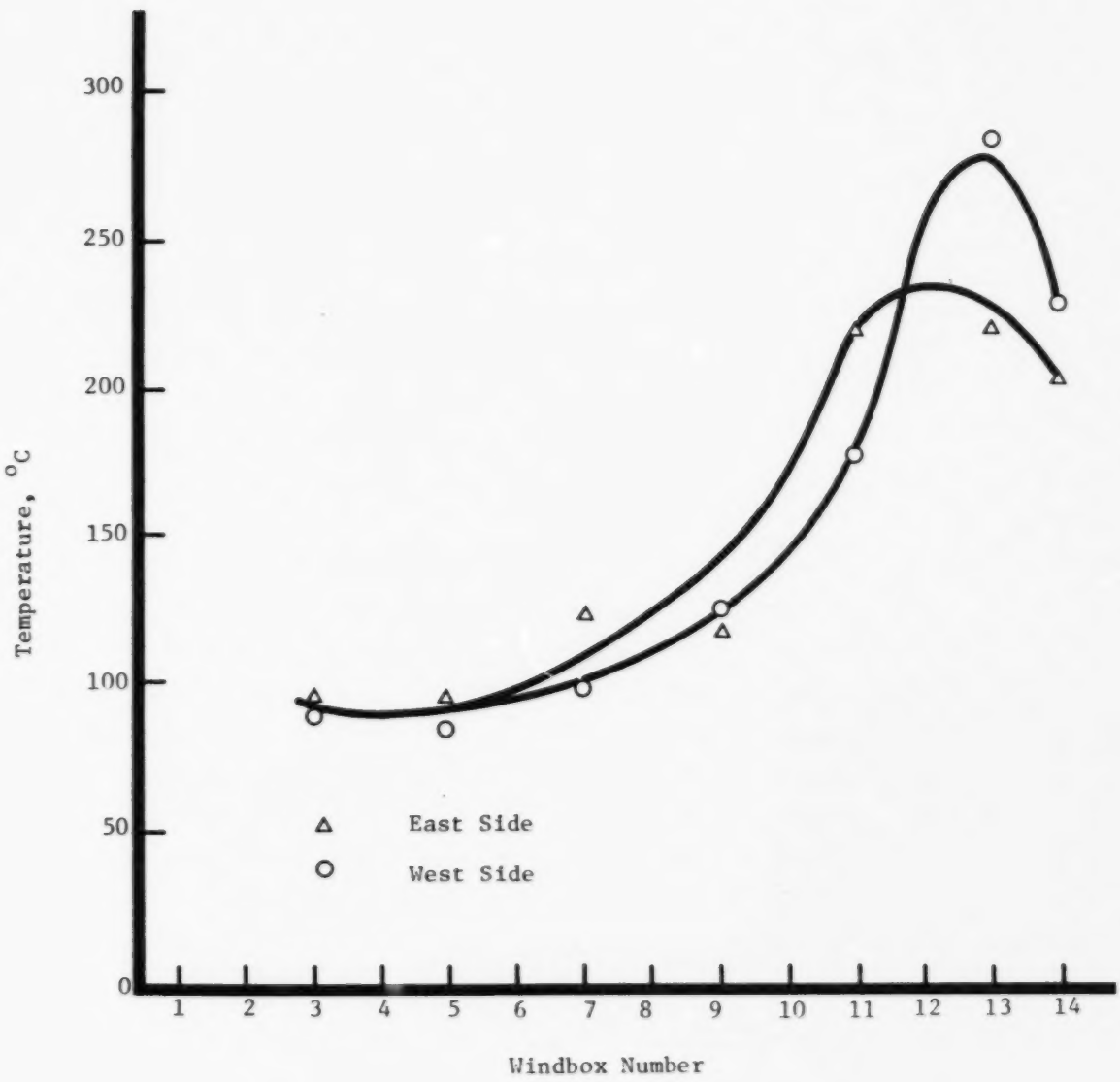



FIGURE 7 STRAND WASTE GAS TEMPERATURE PROFILE - BASE PERIOD

Sinter Strand Operation - Test Results and Discussion (cont'd)

This is not necessarily an abnormal condition; it may reflect leakage more than process conditions. The lower east side temperature at the discharge end of the strand (windboxes 12 - 14) is probably due entirely to leakage. During the test period both sides had virtually the same temperature characeristics along the length of the strand as shown in Figure No. 8. Repairs during the maintenance outage between the two periods reduced leakage in the east side windboxes. The combined windbox temperature data for the two periods are shown in Figure No. 9. Only at the end of the strand (windboxes 12-14) did the temperature differ between the two periods. This reflects the low temperature level of the east side windboxes during during the base period. All curves in Figures 4-6 exhibit typical waste gas profiles for the process. Temperature profiles based on measurements taken at the windboxes during the waste gas sampling given in Table No. 4 correspond to the profile shown in Figure No. 9. However, the actual temperatures tend to run higher during the base period for the last four or five windboxes.

Assuming no other changes in energy input, recycling should produce an increase in waste gas temperature since ambient air is partially replaced by a hotter waste gas. During approximately the first half of the process, an increased gas temperature might not be noted since the raw sinter mix has a high heat capacity which can absorb the additional thermal energy. During the latter stage of the process, however, this is not necessarily true and an increase in waste gas temperature should be observed. All data on individual windbox temperature measurements indicate no significant difference in thermal conditions between conventional and recycle modes of processing changes in energy input. Waste gas temperatures were generally more uniform during recycle which further suggests no problems with process control.

Composition of the waste gas from the individual windboxes, given in Table No. 5 and compared for two periods in Table No. 6 and Figures Nos. 10-12 differed between conventional and recycle modes of operation. Under waste gas recycle the oxygen content decreased and the carbon monoxide and carbon dioxide contents increased. These are the results that would be anticipated. The composition profiles shown in Figures Nos. 10 - 12 are typical of the sintering procesa and exhibit no significant change in shape between conventional and recycle operation. Beyond ignition (windboxes 1 to 3) the waste gas oxygen content was reduced about three percent with recycle out to windbox 10 or 11. After windbox 10 or 11 the reduction in oxygen content decreased from three percent to about two percent at windbox 14. The corresponding changes in other constituents were a four percent increase in carbon dioxide content and 0.15 percent increase in carbon monoxide during most of the process. As with the oxygen, these differences diminished during the latter stage of sintering.

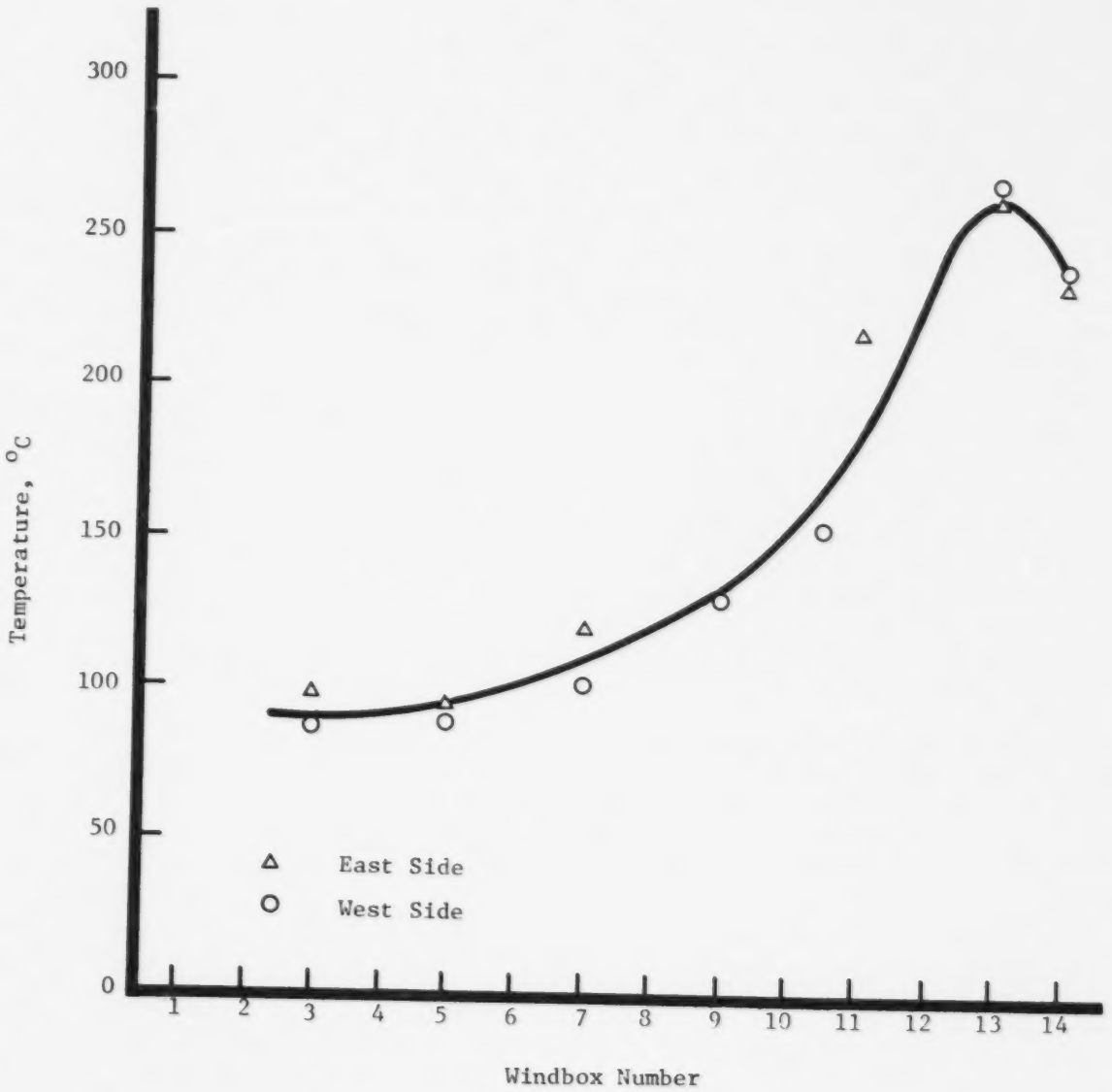



FIGURE 8 STRAND WASTE GAS TEMPERATURE PROFILE - RECYCLE PERIOD

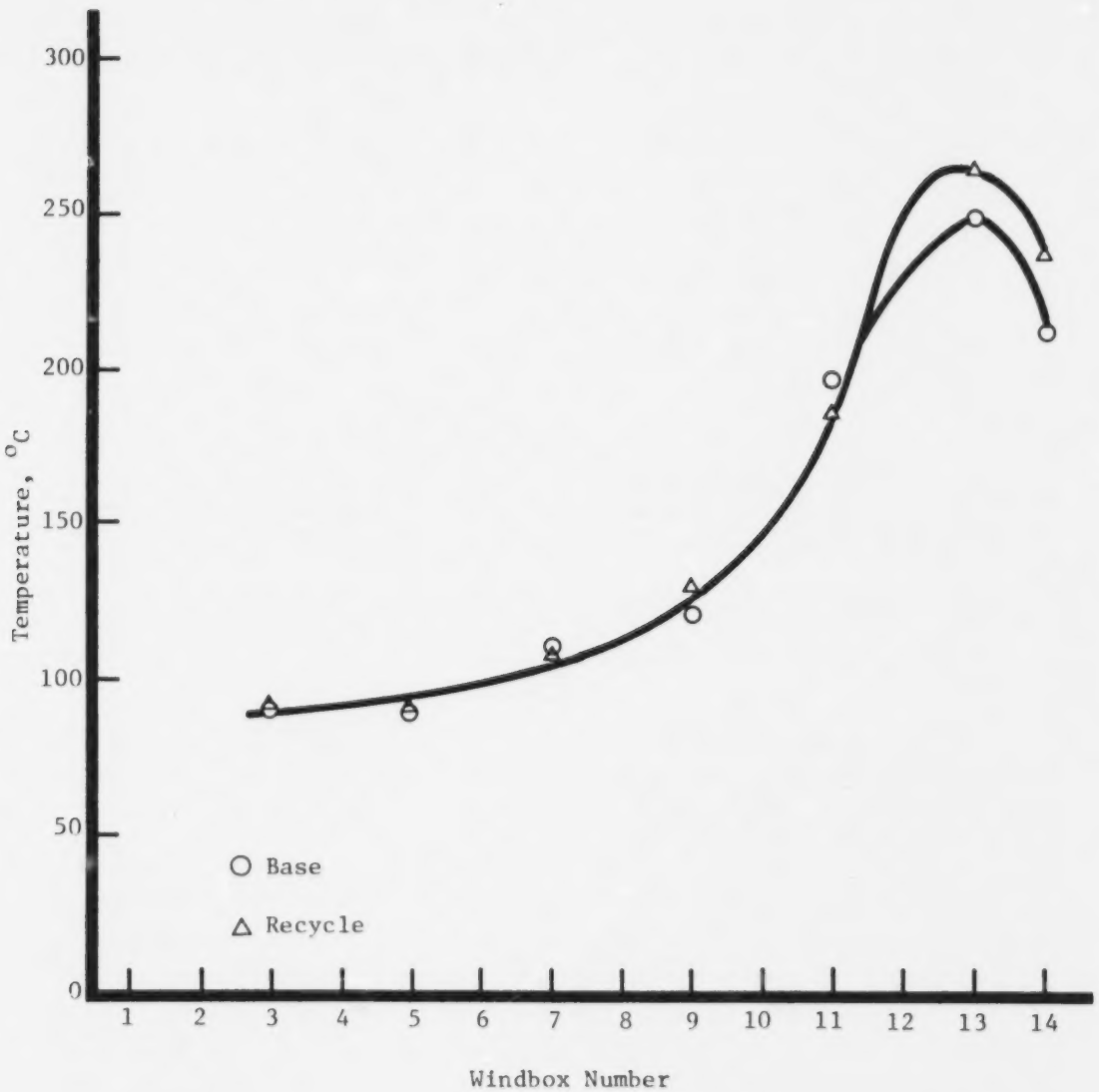



FIGURE 9 COMPARATIVE AVERAGE STRAND WASTE GAS TEMPERATURE PROFILES

TABLE NO. 5
WINDBOX GAS COMPOSITION AND TEMPERATURE

| | BASE PERIOD | | | | | RECYCLE PERIOD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Percent By Volume | | | Temperature | | Percent By Volume | | | Temperature | |
| | $O_2$ % | $CO_2$ % | CO % | °C. | (°F.) | $O_2$ % | $CO_2$ % | CO % | °C. | (°F.) |
| East Side | | | | | | | | | | |
| 1 | 17.5 | 2.5 | 0.24 | 126.7 | (260) | 18.2 | 2.4 | 0.18 | 97.8 | (208) |
| 2 | - | - | - | - | - | - | - | - | - | - |
| 3 | 13.4 | 7.9 | 1.26 | 91.7 | (197) | 13.3 | 10.0 | 0.89 | 90.6 | (195) |
| 4 | 14.1 | 7.3 | 1.05 | 87.8 | (190) | 12.2 | 11.0 | 1.28 | 86.1 | (187) |
| 5 | 13.1 | 9.4 | 1.09 | 97.2 | (207) | 13.3 | 10.3 | 0.96 | 92.2 | (198) |
| 6 | 14.3 | 7.8 | 0.86 | 121.1 | (250) | 12.6 | 12.1 | 0.94 | 98.9 | (210) |
| 7 | 14.3 | 8.3 | 1.07 | 130.6 | (267) | 11.4 | 13.2 | 1.32 | 103.3 | (218) |
| 8 | 16.2 | 6.0 | 0.57 | 148.9 | (300) | 12.0 | 12.3 | 1.27 | 113.9 | (237) |
| 9 | 15.4 | 7.4 | 0.92 | 163.9 | (327) | 12.4 | 11.5 | 1.11 | 139.4 | (283) |
| 10 | 15.4 | 7.3 | 0.81 | 165.6 | (330) | 14.9 | 8.3 | 0.74 | 136.1 | (277) |
| 11 | 17.2 | 3.8 | 0.30 | 225 | (437) | 15.3 | 6.8 | 0.70 | 208.9 | (408) |
| 12 | 17.4 | 4.0 | 0.29 | 240.6 | (465) | 16.8 | 4.5 | 0.16 | 219.4 | (427) |
| 13 | 19.2 | 0.8 | 0.16 | 298.9 | (570) | 17.6 | 3.9 | 0.21 | 228.3 | (443) |
| 14 | 19.3 | 1.3 | 0.05 | 341.7 | (647) | 19.7 | 1.6 | 0.03 | 282.2 | (540) |
| West Side | | | | | | | | | | |
| 1 | 20.7 | - | 0.20 | 76.7 | (170) | 18.2 | 2.6 | 0.42 | 82.2 | (180) |
| 2 | 14.7 | 2.6 | 0.65 | 82.2 | (180) | 15.0 | 6.5 | 0.51 | 87.8 | (190) |
| 3 | 16.3 | 6.1 | 0.65 | 93.3 | (200) | 12.5 | 11.0 | 0.94 | 87.8 | (190) |
| 4 | 14.0 | 8.2 | 0.80 | 93.3 | (200) | 14.6 | 9.8 | 0.73 | 112.8 | (235) |
| 5 | 14.8 | 7.3 | 0.95 | 98.9 | (210) | 9.8 | 14.3 | 1.31 | 93.3 | (200) |
| 6 | 16.5 | 5.2 | 0.87 | 93.3 | (200) | 10.8 | 12.7 | 1.03 | 101.7 | (215) |
| 7 | 14.7 | 7.3 | 0.97 | 123.9 | (255) | 10.9 | 12.5 | 1.00 | 115.6 | (240) |
| 8 | 15.5 | 8.4 | 1.10 | 110 | (230) | 12.0 | 11.0 | 0.88 | 135 | (275) |
| 9 | 14.7 | 7.8 | 1.03 | 148.9 | (300) | 11.7 | 11.4 | 1.01 | 137.8 | (280) |
| 10 | 17.9 | 6.4 | 0.73 | 190.6 | (375) | 13.6 | 9.5 | 0.82 | 171.1 | (340) |
| 11 | 17.5 | 4.7 | 0.71 | 271.1 | (520) | 13.3 | 9.0 | 0.55 | 221.1 | (430) |
| 12 | 19.7 | 1.5 | 0.13 | 246.1 | (475) | 18.4 | 3.7 | 0.27 | 215.6 | (420) |
| 13 | 18.6 | 2.8 | 0.25 | 321.1 | (610) | 14.7 | 7.3 | 0.39 | 248.9 | (480) |
| 14 | 19.5 | 1.3 | 0.20 | 353.3 | (668) | 15.9 | 5.5 | 0.47 | 326.7 | (620) |

TABLE 6.

COMPARATIVE AVERAGE WASTE GAS COMPOSITION (% VOLUME)

| Windbox | CONSTITUENT | | | | | |
|---|---|---|---|---|---|---|
| | OXYGEN | | CARBON DIOXIDE | | CARBON MONOXIDE | |
| | Base | Recycle | Base | Recycle | Base | Recycle |
| 1 | 19.1 | 18.2 | 2.5 | 2.5 | 0.22 | 0.30 |
| 2* | 1.47 | 15.0 | 2.6 | 6.5 | 0.65 | 0.51 |
| 3 | 14.8 | 12.9 | 7.0 | 10.5 | 0.95 | 0.92 |
| 4 | 14.1 | 13.4 | 7.7 | 10.4 | 0.93 | 1.00 |
| 5 | 14.0 | 11.6 | 8.3 | 12.3 | 1.02 | 1.13 |
| 6 | 15.4 | 11.7 | 6.5 | 12.4 | 0.87 | 0.99 |
| 7 | 14.5 | 11.2 | 7.8 | 12.8 | 1.02 | 1.16 |
| 8 | 15.8 | 12.0 | 7.2 | 11.7 | 0.84 | 1.08 |
| 9 | 15.1 | 12.1 | 7.6 | 11.4 | 0.97 | 1.06 |
| 10 | 16.6 | 14.2 | 6.8 | 8.9 | 0.77 | 0.78 |
| 11 | 17.3 | 14.3 | 4.2 | 7.9 | 0.50 | 0.62 |
| 12 | 18.5 | 17.6 | 2.7 | 4.1 | 0.21 | 0.22 |
| 13 | 18.9 | 16.2 | 1.8 | 5.6 | 0.20 | 0.30 |
| 14 | 19.4 | 17.8 | 1.3 | 3.4 | 0.13 | 0.25 |

* - Only west side

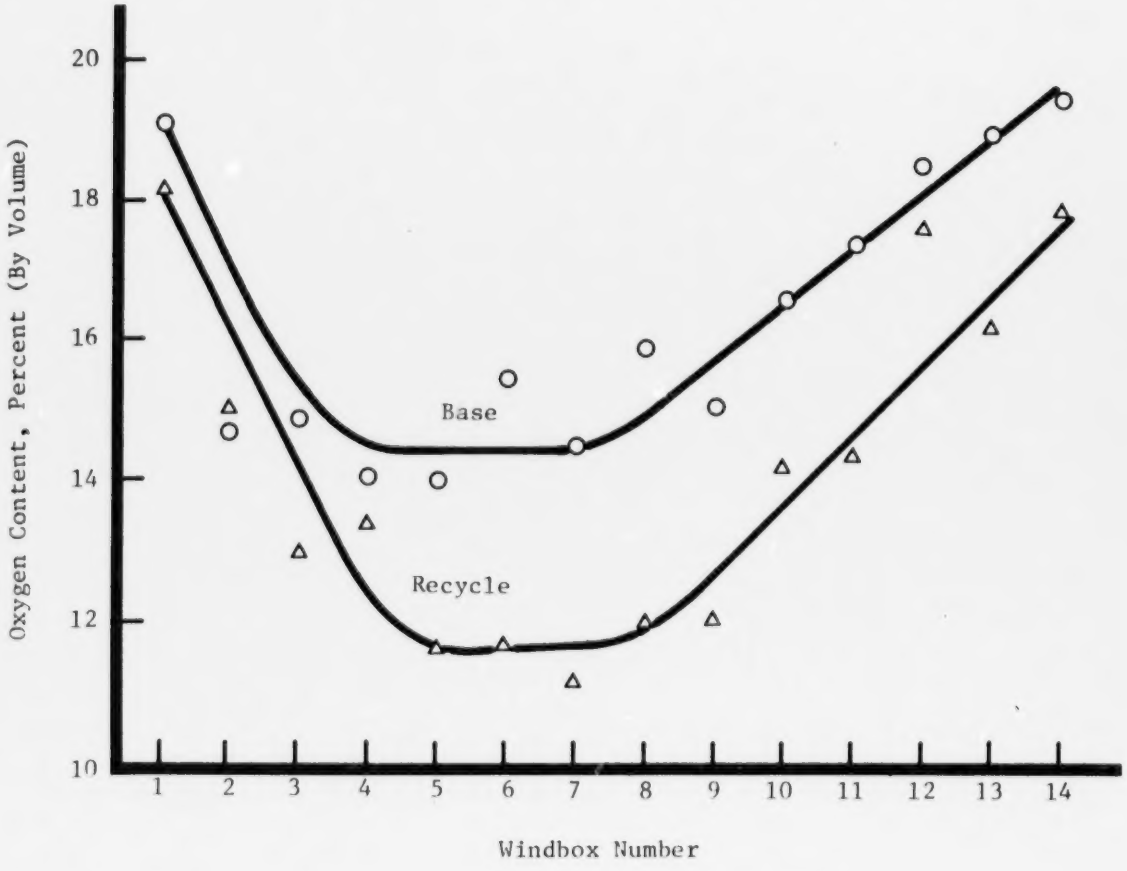



FIGURE 10 COMPARATIVE AVERAGE STRAND WASTE GAS OXYGEN PROFILES

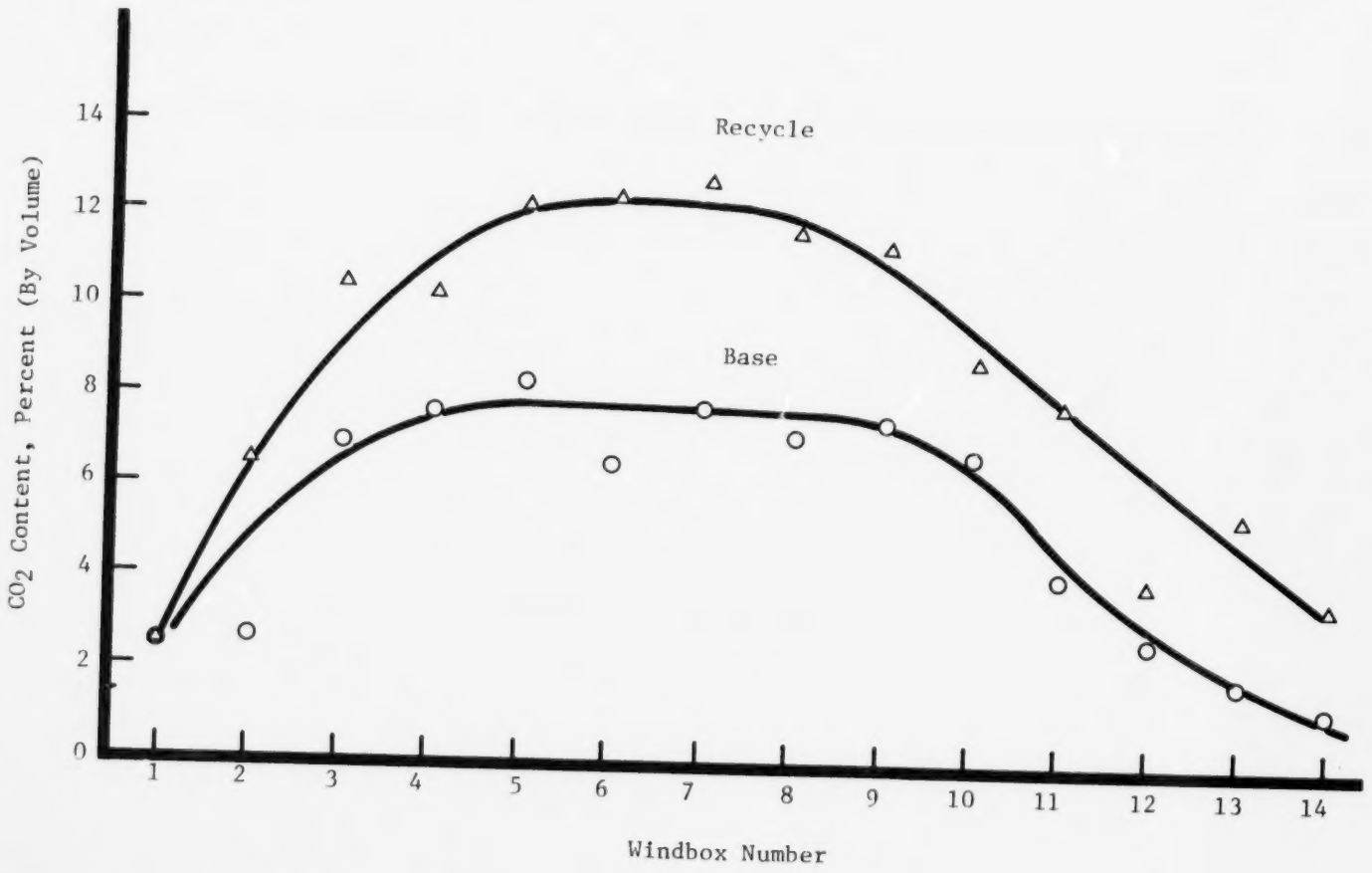



FIGURE 11 COMPARATIVE AVERAGE STRAND WASTE GAS CARBON DIOXIDE PROFILES

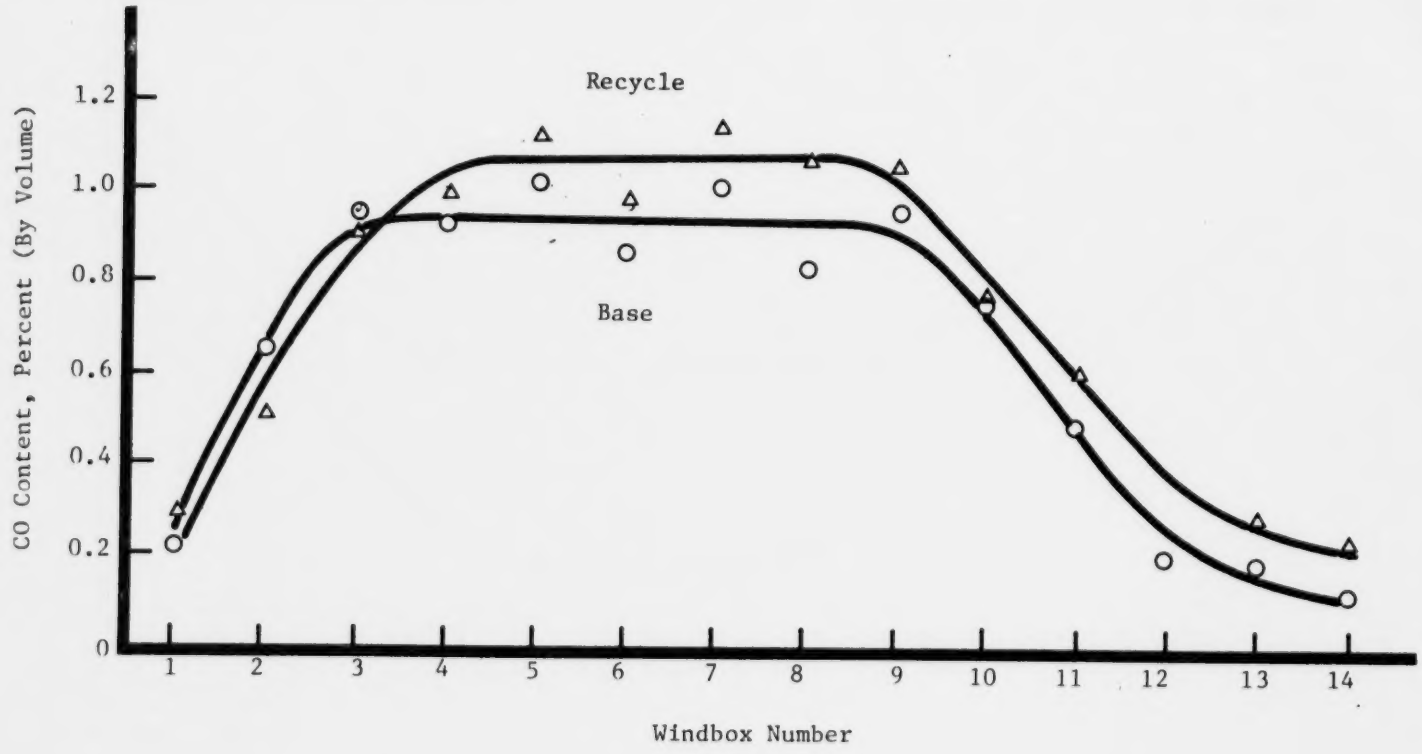



FIGURE 12 COMPARATIVE AVERAGE STRAND WASTE GAS CARBON MONOXIDE PROFILES

Sinter Strand Operation - Test Results and Discussion (cont'd)

Table No. 7 indicates the gas flow rates, temperatures and compositions at the waste gas and recycle gas fans during the base and recycle periods. In addition, the plenum and stack flows, recycle distribution and leakage rate in the windbox system are tabulated.

## Sinter Quality - Test Results and Discussion

The chemical and physical characteristics of the sinter produced during the base and recycle periods are given in Table No. 8. Sinter chemical composition was similar between the two periods. The slightly higher iron oxide content for the recycle period could be due to the restricted oxygen availability decreasing the degree of re-oxidation during cooling on the strand. However, the 10.98 percent value is within the range of iron oxide content encountered under normal processing. Overall chemical variability was similar for the two periods, and is more a function of variation in the composition of the raw materials rather than processing conditions.

Sinter physical quality was indentical for the two periods. While the plus 6.35 millimeter (1/4 inch) screen index is about 1.3 percent lower during recycle, the difference is not statistically significant. For the recycle period, the screen indicies were slightly less variable, but the tumble index slightly more variable. There is no evidence that the use of waste gas recirculation had a significant effect on sinter chemical composition or physical quality.

TABLE NO. 7
FAN DATA

| | BASE PERIOD | | RECYCLE PERIOD | |
|---|---|---|---|---|
| | Mean | ±2 σ | Mean | ±2 σ |
| **Waste Gas Fan** | | | | |
| Flow, $Nm^3/min$ (scfm)(wet) | 8,500 (300,130) | 552 ( 18,990) | 8,374 (295,686) | 735 ( 25,923) |
| Temperature, °C. (°F.) | 107.8 (226) | 32.2 (58) | 116.7 (242) | 11.1 (20) |
| Composition, (% by Volume) | | | | |
| $O_2$ | 17.85 | 0.95 | 16.51 | 1.32 |
| $CO_2$ | 4.17 | 1.78 | 5.00 | 1.24 |
| CO | 0.41 | 0.42 | 0.49 | 0.19 |
| **Recycle Gas Fan** | | | | |
| Flow, $Nm^3/min$ (scfm)(wet) | 7,587 (267,904) | 430 ( 15,200) | 7,456 (263,290) | 885 ( 31,250) |
| Temperature, °C. (°F.) | 108.9 (228) | 29.5 (53) | 113.3 (236) | 18.4 (33) |
| Composition, % by Volume | | | | |
| $O_2$ | 17.58 | 0.88 | 17.05 | - |
| $CO_2$ | 4.06 | 0.94 | 5.09 | - |
| CO | 0.59 | 0.33 | 0.47 | - |
| Pnenum Flow, $Nm^3/min$ (scfm)(wet) | 16,087 (568,034) | 730 ( 25,781) | 15,830 (558,976) | 540 ( 19,061) |
| Stack Flow, $Nm^3/min$ (scfm)(wet) | 16,087 (568,034) | 730 ( 25,781) | 11,801 (416,697) | 887 ( 37,614) |
| Recycle Flow, $Nm^3/min$ (scfm)(wet) | - - | - - | 4,029 (142,279) | 404 ( 14,280) |
| % Recycle | - | - | 25 | 4.4 |
| **Recycle Dist., %** | | | | |
| No. 1 Hood | - | - | 9.0 | - |
| No. 2 Hood | - | - | 16.5 | - |
| No. 3 Hood | - | - | 15.9 | - |
| No. 4 Hood | - | - | 18.6 | - |
| No. 5 Hood | - | - | 18.2 | - |
| No. 6 Hood | - | - | 21.8 | - |
| Recycle Flow Temperature °C. (°F.) | - - | - - | 132.8 (271) | 10.6 (19) |

TABLE 8.

SINTER PROPERTIES - PHYSICAL AND CHEMICAL

| Item | BASE PERIOD Mean | BASE PERIOD ±2σ | RECYCLE PERIOD Mean | RECYCLE PERIOD ±2σ |
|---|---|---|---|---|
| Chemistry, Wt. % | | | | |
| Iron | 51.19 | 1.35 | 51.27 | 1.65 |
| FeO | 9.38 | 1.58 | 10.98 | 1.94 |
| Mn | 0.33 | 0.09 | 0.36 | 0.08 |
| Sulfur | 0.016 | 0.008 | 0.013 | 0.006 |
| $SiO_2$ | 7.37 | 0.63 | 7.25 | 0.98 |
| $Al_2O_3$ | 1.37 | 0.16 | 1.34 | 0.13 |
| CaO | 13.67 | 1.09 | 13.33 | 0.99 |
| MgO | 4.89 | 0.45 | 4.76 | 0.7 |
| Basicity | 2.13 | 0.26 | 2.10 | 0.23 |
| Quality | | | | |
| + 6.35 Millimeter Screen, % | 88.34 | 6.82 | 87.04 | 5.87 |
| + 3.17 Millimeter Screen, % | 96.68 | 2.61 | 96.38 | 2.20 |
| Tumble Index, % | 76.82 | 5.70 | 76.96 | 6.34 |

## Section V-B - Operating Problems

### 1. Windbox Gas Recirculation System

Three significant operating probems were noted during the demonstration phase of waste gas recirculation. These were (1) fan erosion; (2) additional time required for routine maintenance of the sinter machine; and (3) expulsion of particulate and gases from under the sinter machine recycle hood during the use of higher than 25 percent recycle.

Four months after the start-up of the windbox gas recirculation system, an imbalance problem developed in the recycle and waste gas fans. An inspection of these fans revealed that the impellor liners had eroded from a thickness of 9.5 millimeters (3/8 inch) to 3 millimeters (< 1/8 inch) at or near tip of the blade. Impellor wear was a problem prior to the installation of the windbox gas recirculation system and the new fans, but it is apparent that an acceleration of the wear rate occurred as a result of this installation of the new fans.

The new fans operate at a speed approximately twenty-five percent higher than the old fans (900 rpm versus 720 rpm). This equates to an impellor tip speed of 10,092 meters per minute (33,110 feet per minute) for the new fans versus 7,986 meters per minute (26,200 feet per minute) for the old fans.

As a result of this problem it was necessary to implement an intensive maintenance program to restore the eroded areas of the fan impellors during the sinter machine downturns. This program consisted of the application of cladding to the eroded areas, on a weekly basis, using welding rods. The techniques utilized in the welding program are critical in that extreme care must be employed to maintain fan balance.

Efforts were immediately directed toward the minimization of the erosion problem. Replacement of the original impellor liner material with specially hardened steels did not appreciably extend impellor life. It wasn't until the installation of a specially constructed armored plate that the erosion problem subsided. The armored liner consisted of a 3.2 millimeter (1/8 inch) tungsten carbide overlay on an 8 millimeter (5/16 inch) carbon steel plate. This material is presently serving well, and it is anticipated that the past impellor life span of nine to twelve months will increase to two years. The welding program is still necessary on a periodic basis to restore eroded area at (1) the juncture of the tungsten carbide overlay and carbon steel plate; (2) holddown bars and angles at the side and intake end of the liners; and (3) flat head bolts securing the liner plates.

Section V-B - Operating Problems (cont'd)

1. Windbox Gas Recirculation System (cont'd)

The second problem noted during the operation of the windbox gas recirculation system was the increased time required to perform routine repairs and maintenance. Access to the machine is limited since the hood system covers the entire length of the sinter strand. In some instances, such as pallet replacement, the time required to perform routine maintenance tasks have doubled. Visual observations of the sinter bed are also limited due to the hood assembly. This problem is considered inherent with the system, and the advantages of this technology are considered to outweigh this disadvantage.

The third and most important problem during this demonstration concerned the expulsion of particulate and gases from under the sinter machine recycle hood. During the design phase of this system, it was anticipated that the volume of gas returned to the machine would be limited by the oxygen content of the recirculated waste gas. However, in actual practice it was found that recycle rates higher than twenty-five percent resulted in air quality problems in the operating area.

At thirty percent recycle, significant quantities of particulate and gas were discharged into the plant at several locations along the perimeter of the hood system.

The reasons for the recirculation limitation of twenty-five percent are not totally known at this time, but the major contributing factor is leakage to the windbox system. It is estimated that excess air at the rate of fifty percent of the total effluent volume is entering the windbox system via routes other than through the sinter bed. This condition is not uncommon in older sinter machines, since the economic advantage of minimal leakage was not apparent until the 1970's. In an effort to decrease the leakage rate, increase the windbox recirculation rate and further reduce the requirements for the final air pollution control device, the Company has initiated programs for improved sealing facilities at the pallet train and windbox junctures of the sinter machine. In addition, an aggressive maintenance program has been established for the repair of leakage in the windbox collecting main and cyclone systems. Repair of leakage from erosion in these areas is a never-ending, but essential, task.

Section V-B - Operating Problems (cont'd)

2. Gravel Bed Filter System

Many problems were confronted during the early stages of optimization of the gravel bed filter system which have been totally resolved or minimized. Observations conducted immediately after the start-up of the system disclosed that a problem existed with the hydraulic downcomer valves which isolate the incoming Sinter Plant gas from the gravel bed backflush air cleaning system (see Figure 4). Occasions arose in which individual downcomer valves were observed in a partially open position. When this condition occurred the gravel bed filter system was short-circuited and uncleaned incoming gas from the sinter machine bypassed the filter module to the backflush cyclones. As a result, the volume and velocity of the backflush air available for bed cleaning was drastically reduced and satisfactory bed cleaning was not achieved. It has been determined that two downcomer valves in the open position render the bed cleaning cycle ineffective. It should be noted that this installation was the first to utilize this valve design and also the first to utilize valves on the inlet (dirty) side of the gravel bed filter. Forty-eight valves out of a total of seventy-two valves in the system were affected.

As a part of the original design, a deflector baffle was welded to one side of the disc-type downcomer valve to minimize dust deposits on adjacent ductwork which might hinder valve travel. This deflector baffle caused a weight imbalance to exist in the valve and the single-point guide system was insufficient to maintain rigid vertical travel. Once the valve left the guide system it was free to rotate when in the raised position. If rotation occurred, the deflector baffle struck the angular bottom of the valve housing during the downward stroke of the valve, and travel was restricted. Experimentation indicated that this condition is improved by the addition of a counterweight on the valve opposite the deflector baffle. The counterweight stablizes the valve during travel and the program to install the counterweight on each of the forty-eight valves with the deflector baffle design has been completed.

2. Gravel Bed Filter System (cont'd)

Modifications have also been incorporated in the valve guiding system and the hydraulic cylinder to eliminate the problem of restricted travel. The shafts of the hydraulic cyclinders were extended approximately twenty inches and a pedestal was fabricated to raise the hydraulic cylinder, thus minimizing its subjection to the dirty atmosphere. The pedestal consists of a section of three inch pipe with a rectangular piece of plate welded to each end. After welding, two slots 180 degrees apart were machined the full length of the pipe. The slots serve as a guide for a pin which is threaded in the shaft extension. A supplemental advantage of the improved guiding system was the incorporation of external indication of valve position, which was previously non-existent.

A second problem also associated with the backflush cycle was the replacement requirements for the filter media support screens. The necessity for replacement generally resulted from damage caused by insufficient clearance between the rake and the screen. In addition, it became evident that the tear resistance of the screens was inadequate for this application. The adjustment of rake clearance and the installation of heavier gauge support screens have essentially eliminated this problem.

A third problem of consequence developed during the early stage of gravel bed filter operating due to the build-up of dust on the garnet filter media. After three months of operation, observations indicated that the filter beds had doubled in depth from the original 100 millimeters (4 inches) to approximately 200 millimeters (8 inches). At that time the increased bed depth began affecting the system in that individual modules became inoperative due to overloading of the rakes during the backflush cycle.

2. Gravel Bed Filter System (cont'd)

It became necessary to remove a portion of the filter media from the beds in order to place them back in operation. Results from testing conducted during this time interval indicated a monthly growth rate for the garnet filter media of 25 percent on a weight basis. Visual observations indicated that this growth occurred at different rates for individual particles in the bed. It became evident that the garnet filter media had an inherent disadvantage of rapid growth in this environment.

Additional testing was immediately initiated to document the physical changes of various types of filter media in the same environment. Observations continued during subsequent months to document the physical characteristics of other filter medias contained in selected test modules of the gravel bed filter system. Samples of media from these test modules were removed periodically, and physical analyses were performed to establish growth trends. This testing demonstrated that of all the filter medias tested, steel grit was superior with respect to growth trends and filtering efficiency. Based on these conclusions, the gravel bed filter system was temporarily shut down and the garnet filter media was totally replaced with steel grit filter media.

An inspection of the modules containing either the garnet or steel grit filter media also revealed a severe problem of blinding and adhesion of sinter dust to form a 1 to 10 millimeters (0.04 to 0.4 inches) cake on the support screens. Since clearance between the rakes and the support screens is maintained at approximately 13 millimeters (0.5 inches) to avoid screen damage, this layer is not disturbed during the backflush cleaning cycle. Once the screens start to blind, uneven, high velocity backflushing of the bed occurs and sections of the support screens are left without media cover after the completion of the cycle. This phemomenon is of a very serious nature since it causes short-circuiting of the system and results in a reduction in particulate removal efficiency.

It has been concluded that the principal cause of the screen blinding problem is the condensation of moisture on the screens and the combination of this moisture with the lime-rich sinter dust in the waste gas. Since there are numerous interrelated factors which could contribute to this problem, it has been difficult to implement a total solution. The factors presently hindering the optimized operation of the system could be one or any combination of the following:

Section V-B - Operating Problems (cont'd)

2. Gravel Bed Filter System (cont'd)

(a) Insufficient backflush air.
(b) Malfunction of backflush air preheat system.
(c) Reaction of coke oven gas consitutuents with sinter plant dust.
(d) Inadequate raking action.
(e) Frequency of start-up and shutdown modes of operation.
(f) Fluctuating incoming waste gas temperatures.

During the early operational stage of the system, it was suspected that the backflush fans were not of a sufficient capacity to thoroughly purge the bed of dust. An investigation indicated that these fans were of marginal capacity. However, it was recognized that a critical balance must be maintained to achieve the highest velocity possible through the bed without displacing the filter media. A program to replace the backflush fans was implemented prior to the decision to change from garnet to steel grit filter media. The success of this fan replacement program is indeterminate but in retrospect its implementation was essential in view of the conversion to the higher specific gravity steel grit filter media.

The backflush preheat system appears to be one of the significant causes of screen blinding since it has not yet been proven to perform with adequate reliability. Due to condensed deposits from the coke-oven gas in the valve train ahead of the burner system, malfunctions have continued to occur, although less frequently in the summer than in the winter months. The re-design and conversion of the piloting system to natural gas was a major step in obtaining improved reliability, but additional steps are required. It is evident that any program to clean up the coke-oven gas would not only assist in improving the reliability of the backflush preheat system, but would also minimize any inter-action which may be occurring between the combusted coke-oven gas and the collected sinter dust. An effort to improve the quality of the coke-oven gas via the installation of a baffled separator in the supply line was only moderately successful. The Company is presently testing a chemical additive which is injected in the coke-oven gas feed line upstream of the backflush preheat system. Thus far, this program has shown promise in improving the reliability of the preheat system.

2. Gravel Bed Filter System (cont'd)

The influence of the raking action on the screen blinding problem is not known at this time. However, it has been concluded that the redesign of rake tines could improve the effectiveness of the back-flushing cycle, and a program to modify one module for experimental purposes will be implemented in the near future.

The frequency of the start-up and shut-down modes of the sinter machine, and the fluctuation of incoming waste gas temperatures to the gravel bed filter system are a function of production schedules and equipment maintenance and malfunction. These factors are suspected to be the most significant contributors to the screen blinding problem since the probability of dew point condensation from the waste gas to the filter beds is extremely high. As would be expected, the probability of dew point condensation is much higher in the winter than in the summer months. Unfortunately, these conditions cannot be totally avoided unless the gravel bed filter system is by-passed during these critical intervals.

The detrimental effects of the screen blinding problem on the operating reliability and performance cannot be over-emphasized. Under optimized conditions, the gravel bed filter system has demonstrated the capability of producing an effluent concentration of approximately 68.6 mg/$Nm^3$ (0.03 grains/dscf) of particulate. During periods of malfunction with blinded screens, the effluent concentration is more than tripled.

In order to establish the requirements for improved reliability and performance of the system, a testing program was initiated utilizing one filter module. This testing program included an expansion of fan capacity for the gravel bed filter system to permit the treatment of additional effluent volume from the sinter machine.

Section V-B - Operating Problems (cont'd)

2. Gravel Bed Filter System (cont'd)

One module in the gravel bed filter system was modified to permit monitoring of inlet and outlet dust loadings. The volume directed to this module was increased to the design flux rate of 36.6 cubic meters per minute per square meter of bed area (120 cubic feet per minute per square foot of bed area). Experience gained on this and other applications of gravel bed filtration has indicated that the effluent quality will be improved by the increased velocity through the bed since the particle agglomeration process is enhanced. It was therefore concluded that the system can accept the additional flow of waste gas providing that the fan capacity is expanded.

Additional test work was directed toward establishing the effect of filter media particle sizing and backflush air volume on the reliability and performance of the system. This testing concluded that the steel grit filter media sizing could be increased from a nominal diameter of 1.04 millimeters (0.041 inch) to 1.40 millimeters (0.055 inch) without a sacrifice in effluent quality. In addition, the testing indicated that a 10 percent increase in backflush fan speed would be beneficial. The use of large media will permit the conversion to a larger opening support screen which should reduce the opportunity for the screen to blind. An equally important advantage in increasing the media size is that the pressure drop will be lower for a given gas volume. In addition, the use of large filter media in combination with increased backflush fan speed will allow more efficient cleaning of the beds.

Based on these test results the following revisions to the system will be implemented by July 1979:

1. The existing gravel bed filter fan will be replaced to increase the capacity from 4531 normal cubic meters per minute (160,000 standard cubic feet per minute) to 6800 normal cubic meters per minute (240,000 standard cubic feet per minute).

2. The steel grit filter media will be changed from a nominal diameter of 1.04 millimeters (0.041 inch) to 1.40 millimeters (0.055 inch).

Section V-B - Operating Problems (cont'd)

2. Gravel Bed Filter System (cont'd)

3. The filter media support screens will be changed from 0.89 millimeter diameter wire, 0.81 millimeter clear opening (15 mesh 0.035 inch diameter wire, 0.032 inch clear opening) to 1.04 millimeter diameter, 1.27 millimeter clear opening (11 mesh 0.041 inch diameter wire, 0.050 inch clear opening).

4. The speed of the existing backflush fans will be increased by 10 percent from 2055 to 2260 revolutions per minute.

It is anticipated that the above program will significantly improve the operating reliability and performance of the gravel bed filter system. However, it is recognized that a major factor in obtaining sustained operation is the implementation of a comprehensive preventative maintenance program in screen cleaning. In past practices, such a program was not feasible due to inadequate material handling facilities to remove the filter media from the module to permit access for screen cleaning. For this reason, the above program was expanded to include the installation of a filter media material handling and storage system sized to permit the cleaning of the screens in four modules (eight beds) in an eight-hour period. This installation will facilitate the implementation of a preventative maintenance program of screen cleaning during the scheduled weekly sinter machine down turn on a repeat cycle of six weeks.

Section V-C - Environmental Aspects

As defined in the scope of work for this contract, testing and evaluation in various modes of operation for a sinter plant windbox exhaust gas system were accomplished. These modes included (1) a base study (no windbox gas recirculation ); (2) optimum recycle of windbox gas system; (3) no windbox gas recirculation with gravel bed filtration; and (4) optimum recycle of windbox gas and gravel bed filtration. These studies were performed on Weirton Steel Division's No. 2 Sinter Machine and included such parameters as flow rate, gas composition, particulate, sulfur dioxide and hydrocarbon determinations for each of the above mentioned test modes. The goal of the contract endeavor was directed toward lowering total air pollutants from steel industry sinter machines using windbox gas recirculation and/or gravel bed filtration. This section presents the final results of these tests as related to the environmental benefits realized from the use of these technologies.

## TEST PROGRAM

### Test Plan (General)

In order to expedite the completion of the testing and evaluation requirements in the contract, testing was conducted in two distinct phases. Phase A involved only the base study (no recycle) and optimization of the recycle system with the submission of a draft interim report to the Environmental Protection Agency, while Phase B dealt with gravel bed filtration and recycle or no recycle of windbox gases. Phase A testing occurred in August and September of 1977 and Phase B during late July 1978. Gravel bed operations during Phase A were not included in the interim report due to problems encountered in its operation. These problems have been discussed in detail in Section V-B of this report.

### Test Plan (Phase A; Sinter Machine Operation With and Without Windbox Recycle)

Due to the configuration of the Windbox Recycle System it was necessary to traverse several locations to determine recycle flows. In addition, the configuation of the ductwork did not present ideal sampling conditions. To minimize these problems, three traverse stations were selected; (1) prior to the waste gas fan; (2) prior to the recycle fan; and (3) the recycle ductwork leading back to the machine (see Figure 13). The primary sampling station selected for Phase A testing was the No.1 Traverse Station(Waste Gas fan) which was the only truly vertical run of ductwork in the system. All other locations were horizontal runs which presented problems inherent with operating a sampling train in a vertical position and potential severe stratification of particulate concentrations.

Once the selection of the primary sampling station was finalized a second problem had to be reconciled. The variability of charge materials to the sinter machine could have a significant effect on the sampling results. In order to minimize these problems a test schedule was arranged so that the recycle and non-recycle modes could be sampled on the same day. Velocity traverses, gas composition samples, particulate sampling, raw materials composites, sinter composites and condensible organics were collected for each mode of operation on each sampling day. Sulfur dioxide samplings were performed on the following day after the particulate determination. Nine complete sets of sampling data were collected. On any day when the complete test of each mode could not be accomplished the collected data were not used in the analysis.

Section V-C - Environmental Aspects (cont'd)

Test Program (cont'd)

Test Plan (Phase B; Gravel Bed Filtration With and Without Windbox Recycle)

Two additional traverse locations: (1) inlet of gravel bed filters; and (2) gravel bed stack discharge, were selected for the completion of Phase B. The three Phase A traverse stations were utilized to determine flow distributions (1) prior to waste gas fan; (2) prior to the recycle fan; and (3) the recycle ductwork leading back to the machine. Test schedules were arranged to accomplish complete testing of the recycle and non-recycle operational modes within the same day. On any day when the complete test of each mode could not be accomplished due to equipment failure or operational interruptions, the collected data were not used in the analysis.

Testing Procedures (Stack Gas Flow Rates)

Under recycle conditions twenty-four point velocity traverses were performed at each of the three traverse stations (Figure No. 13). Total flow was obtained by adding the measured flow of the waste gas and recycle fans. The amount of recycle was then determined by measuring the volume sent back to the sinter machine hood system. The stack gas volume under no recycle conditions was simply an addition of the waste gas and recycle fan volumes. All gas velocity traverses were made according to Reference Methods 1 and 2 as published by the Environmental Protection Agency in the FEDERAL REGISTER. (3) A summary of the measurements for each traverse location are included in the Appendix Tables 22 through 24.

Testing Procedures (Waste Gas Composition)

Waste gas grab samples were collected before each sampling run in 250 ml. glass sampling cylinders equipped with side arms for convenient extraction of a syringe sample. The gas cylinder samples were then transferred to the laboratory and analyzed using a Model 900 Perkin-Elmer Gas Chromatograph, calibrated with gases of a similar composition. The analyses included oxygen, carbon dioxide, carbon monoxide and nitrogen. Detailed results are included in the Appendix on the sampling summary sheets.

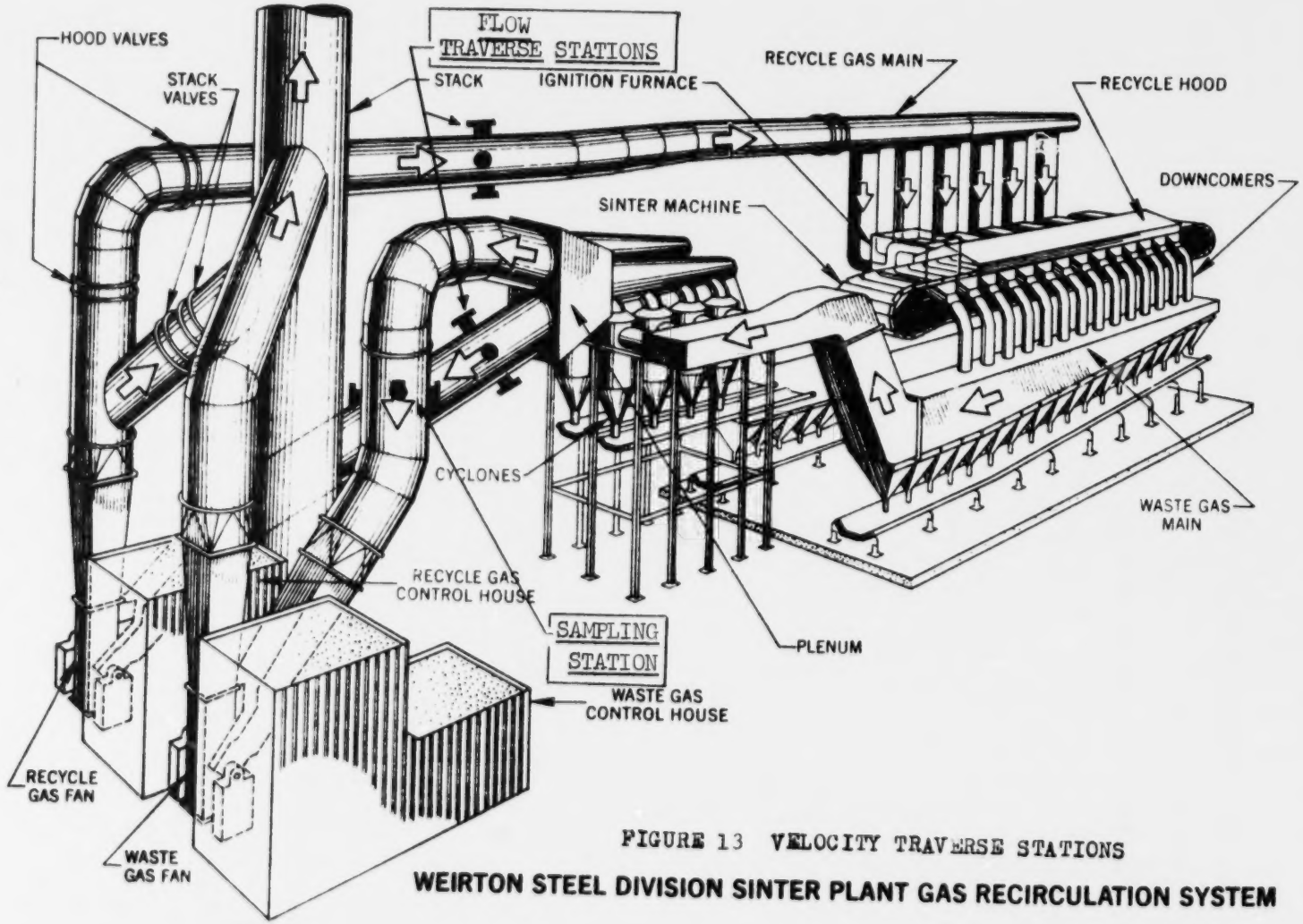



FIGURE 13 VELOCITY TRAVERSE STATIONS

**WEIRTON STEEL DIVISION SINTER PLANT GAS RECIRCULATION SYSTEM**

Section V-C - Environmental Aspects (cont'd)

Test Programs (cont'd)

Testing Procedures (Particulates)

Particulate sampling was performed employing a standard U.S. Environmental Protection Agency Method 5 (4) sampling train assembly as indicated in Figure No. 14. Minor modifications, such as the use of stainless steel liner and filter holder were used. A five-foot heated probe was utilized in order to traverse sample in four directions. In addition to the front half or particulate collection half, an impinger assembly was used. It consisted of four impingers in series, the first two containing 200 ml. of distilled water each, the third empty and the fourth containing 200 grams of silica gel. The impinger assembly was utilized in order to measure waste gas moisture and condensable hydrocarbons. Traverse sampling included twelve points on a diameter or twenty-four total points. All conditions and procedures, as specified by Method 5, were followed as closely as possible during the sampling program.

Testing Procedures (Sulfur Dioxide)

A sampling train was assembled according to the specification of U. S. Environmental Protection Agency Reference Method 6 published in the FEDERAL REGISTER (5) (see Figure No. 15). The option of using Greensburg-Smith bubblers and impingers was employed. In addition the train consisted of a heated probe with three inch fiber glass filter, impinger train, vacuum pump and gas meter. The probe was positioned in a pre-selected location and the waste gas sampled at a constant rate. The impinger train consisted of four impingers, the first containing 200 ml. of eighty percent isopropanol, the second and third 200 ml. of three percent hydrogen peroxide and the last impinger 200 grams of silica gel. After completion of the sampling run the isopropanol was discarded and the hydrogen perioxide transferred to the laboratory for sulfur dioxide analysis using the prescribed barium-thorin titration method.

Testing Procedure (Hydrocarbons)

In an effort to establish a mass balance for condensable organics associated with sinter production, three sampling locations were selected in Phase A testing: (1) raw material mix as fed to the sinter machine was composited during each sampling run; (2) sinter product was collected in a likewise manner; and (3) waste gas condensables were collected using the Method 5 particulate sampling train. The impinger catch was analyzed for organic condensables. All samples collected were submitted to the laboratory and analyzed using a choloroform-ether extraction method for condensable organic emissions for sinter plants. (2) The raw materials and sinter

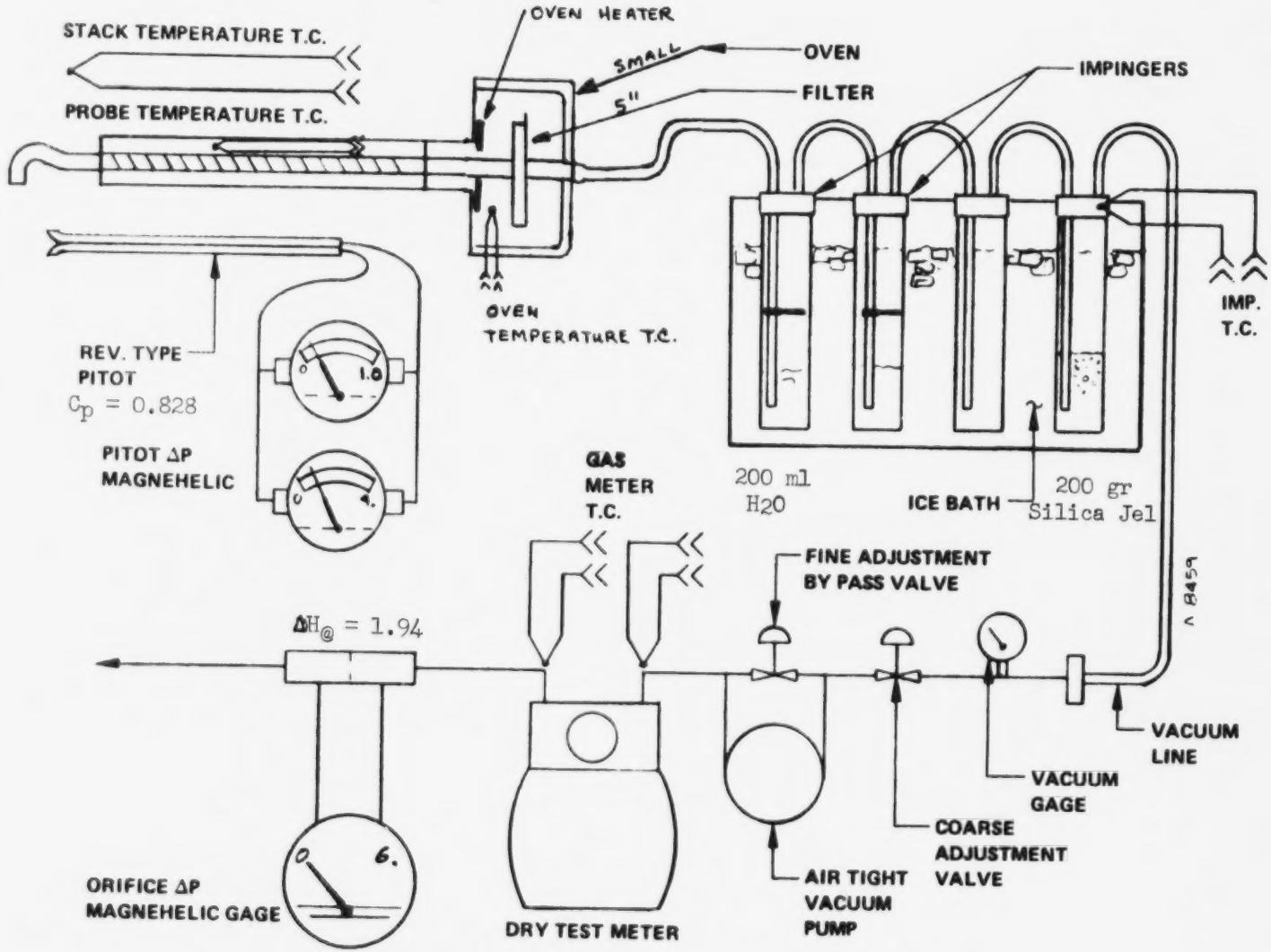
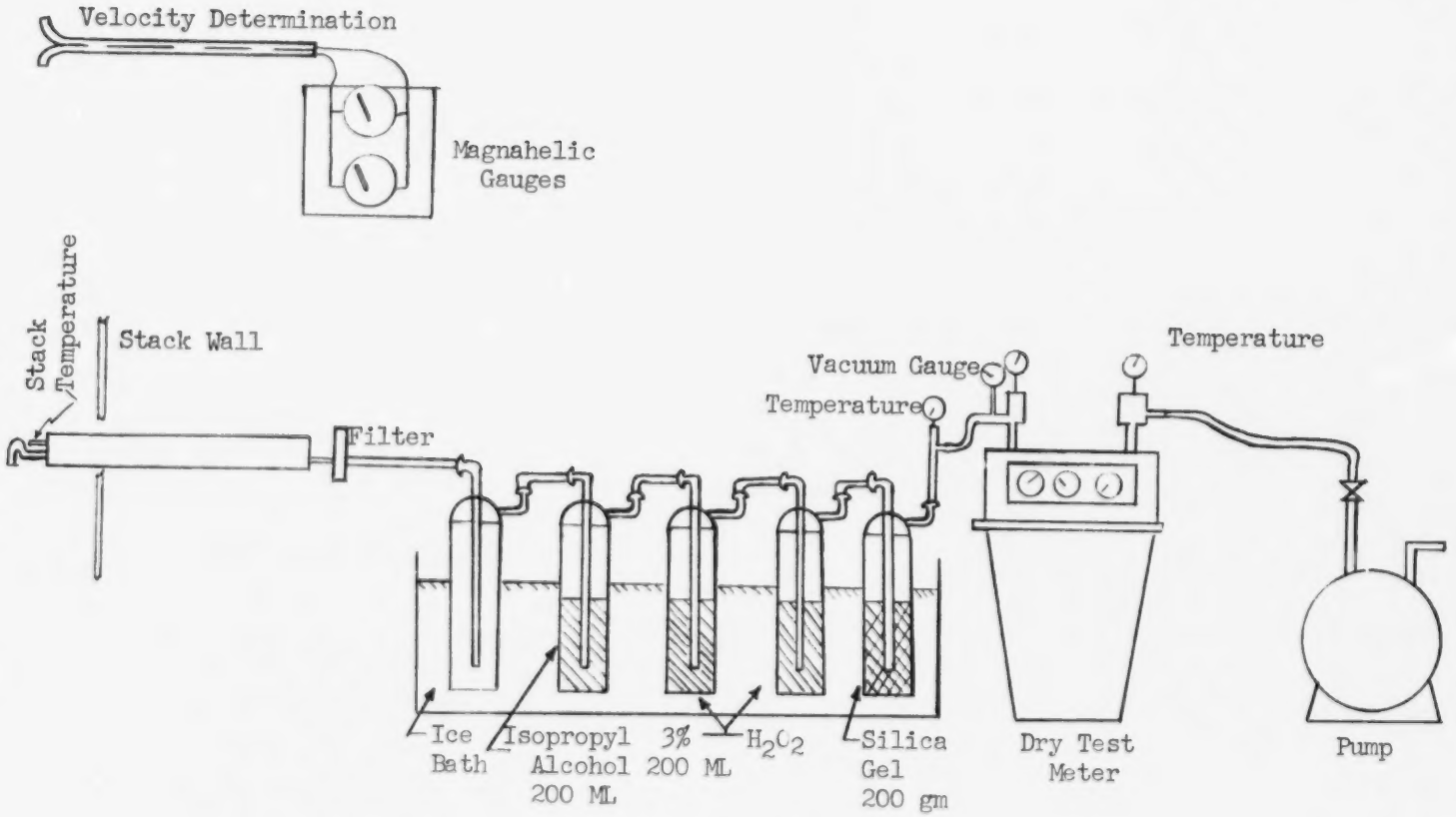



*Figure 14*
*EPA - Method 5 Sampling Train*

FIGURE 15 - SAMPLING TRAIN FOR $SO_2$ DETERMINATION



Test Program (cont'd)

Testing Procedure: (Hydrocarbons) (cont'd)

product were grab sampled at frequent intervals during the testing. The samples collected for each test period were thoroughly mixed and quartered in preparation for analyses by the gravimetric-extraction method. The pre-weighted samples were extracted utilizing chloroform and ether in a soxhlet apparatus. The extract was processed by volume reduction through distillation and drying, and the quantity of organic material was determined gravimetrically. Representative samples were very difficult to obtain and several data points had to be discarded as suspect. Phase B testing did not include raw material or product samples. Hydrocarbon determinations were made only of the inlet and discharge gas streams from the gravel bed system.

## TEST RESULTS

### Phase A Testing (Particulates)

Test Mode No. 1; Base Study - Sampling of the main windbox gas system with no recirculation was performed to determine the emission rate without controls. With no recycle of waste gas to the sinter machine an average particulate concentration of 1182 mg/$Nm^3$ (0.515 grains/dsdf) resulted. Discharge flow rate was measured at 14240 $Nm^3$/min. (503,197 dscfm). The calculated mass particulate emission rate, based on these measurements, was 1007 kg/hr (2215 lbs/hr), or 3.2 g/kg (6.4 lbs/ton) of sinter strand feed (refer to Tables Nos. 9 and 10).

Test Mode No. 2; Windbox Recycle - Sampling tests performed during recirculation of an average of 25 percent of the waste gas resulted in an average particulate concentration of 1094 mg/$Nm^3$ (0.477 grains/dscf). This concentration and an average discharge gas flow of 10330 $Nm^3$/min. (365,025 dscfm) produced a particulate mass emission rate of 681 kg/hr (1498 lbs/hr), which is equivalent to 2.17 g/kr (4.34 lbs/ton) of sinter strand feed (refer to Tables Nos. 9 and 11).

Comparison of the test results for the two operational modes indicates a mass reduction of thirty-two percent of the particulate matter emitted from the main windbox gas system. A slight decrease in concentration during recycle was noted.

Section V-C - Environmental Aspects (cont'd)
Test Results (cont'd)

Phase B Testing (Particulates)

Test Mode No. 3; Gravel Bed With No Windbox Gas Recirculation - Sampling of the inlet to the gravel bed filters resulted in an average particulate emission rate of 1299 mg/$Nm^3$ (0.568 grains/dscf). This concentration and a flow rate of 2569 $Nm^3$/min. (90,744 dscfm) produced a loading 195.9 kg/hr (431.4 lbs/hr).

Outlet stack testing simultaneous with inlet samples indicated an average particulate emission rate of 146.7 mg/$Nm^3$ (0.064 grains/dscf). This concentration and a flow rate of 3309 $Nm^3$/min. (116,854 dscfm) resulted in a mass loading of 30.3 kg/hr (66.7 lbs/hr) (see Table No. 12 for individual test results).

The results of the tests indicated an average reduction of eighty-five percent across the gravel bed filters with a range of seventy percent to ninety-two percent of particulate removal.

Test Mode No. 4; Gravel Bed With Windbox Gas Recirculation - Particulate concentrations were determined while maintaining an average recycle rate of 24.8 percent. The inlet to the gravel bed filter system contained an average 1565 mg/$Nm^3$ (0.68 grains/dscf). A flow rate of 2419 $Nm^3$/min. (85,377 dscfm) and this concentration resulted in a mass loading of 234.7 kg/hr (517 lbs/hr).

Outlet stack gas samples simultaneously taken with the inlet samples showed a concentration of 156 mg/$Nm^3$ (0.068 grains/dscf). This concentration and an average flow rate of 3096 $Nm^3$/min. (109,355 dscfm) resulted in a mass loading of 31.7 kg/hr (69.7 Lbs/hr) in the stack discharge. (see Table No. 13 for individual test results).

The average particulate removal efficiency during this mode of operation was eighty-seven percent with a range from eighty-one percent to ninety-five percent.

Phase A Testing (Sulfur Dioxide)

Test Mode No. 1 - With zero recycle the waste gas steam contained 320 mg/$Nm^3$ (0.14 grains/dscf) of sulfur dioxide. This concentration and a flow rate of 14,240 $Nm^3$/min. (503,197 dscfm) produced a sulfur dioxide emission rate of 271 kg/hr (597 lbs/hr), which is equivalent to 0.86 g/kg (1.72 lbs/ton) of sinter strand feed (see Tables Nos. 9 and 10).

Section V-C - Environmental Aspects (cont'd)

Test Results (cont'd)

Phase A Testing (Sulfur Dioxide) (cont'd)

Test Mode No. 2 - Results of the testing effort for sulfur dioxide indicated a concentration of 350 mg/$Nm^3$ (0.153 grains/dscf) at a 25 percent recycle rate. This concentration combined with an average waste gas discharge rate of 10,330 $Nm^3$/min. (365,025 dscfm) produced a sulfur dioxide emission rate of 223 kg/hr (491 lbs/hr) which equates to 0.71 g/kg (1.42 lbs/ton) of strand feed (see Tables Nos. 9 and 11).

Comparison of the test results for the two operational modes indicates a mass reduction of seventeen percent of the sulfur dioxide emitted from the main windbox gas system. A slight increase in concentration during recycle was noted.

Phase B Testing (Sulfur Dioxide)

Test Mode No. 3 - Sulfur dioxide concentrations in the inlet gas of the gravel bed filter system averaged 175.2 mg/$Nm^3$ (0.076 grains/dscf). The mass loadings based on a measured average flow of 2569 $Nm^3$/min. (90,744 dscfm) was 27.0 kg/hr (59.5 lbs/hr).

Stack gas measurements indicated a concentration of 244.3 mg/$Nm^3$ (0.1 grains/dscf). Mass emission rate calculated at a measured stack flow of 3309 $Nm^3$/min (116,854 dscfm) resulted in an average of 45.5 kg/hr (100.2 lbs/hr) (see Table No. 12).

The increase in sulfur dioxide across the gravel bed filters was due to the use of coke oven gas to preheat backflush air.

Test Mode No. 4 - Inlet gravel bed sulfur dioxide average concentrations with an average 24.8 percent recycle operational mode were 257 mg/$Nm^3$ (0.112 grains/dscf). This concentration and a flow rate of 2419 $Nm^3$/min. (85,377 dscfm)resulted in a mass sulfur dioxide emission rate of 35.5 kg/hr (78.3 lbs/hr).

Stack outlet samples produced an average concentration of 280.5 mg/$Nm^3$ (0.122 grains/dscf). A flow rate of 3096 $Nm^3$/min (109,355 dscfm) resulted in a mass loading of 52.1 kg/hr (114.6 lbs/hr) (see Table No. 13). As in the case of Test Mode No. 3, an increase in sulfur dioxide occurred across the filter due to the utilization of coke oven gas as a fuel.

TABLE NO. 9
SUMMARY TEST RESULTS
(METRIC UNITS)

DESCRIPTION: Test Mode No. 1 - Base Study of Uncontrolled Sinter Machine Operation
Test Mode No. 2 - Optimum Recycle of Main Windbox Waste Gas
Test Mode No. 3 - Gravel Bed Filtration Only
Test Mode No. 4 - Optimum Recycle and Gravel Bed Filtration Combination

| | TEST MODE | | | |
|---|---|---|---|---|
| | No. 1 | No. 2 | No. 3(1) | No. 4 |
| Sinter Charge Rate, MTph | 314 | 314 | 320 | 320 |
| Sinter Product Rate, MTph | 186 | 186 | 190 | 190 |
| Recycle % | 0 | 25.0 | 0 | 24.8 |
| Discharged to Atmosphere, $Nm^3/min$ | 14,240 | 10,330 | 3,309 | 3,096 |
| Particulate, $mg/Nm^3$ | 1,183 | 1,094 | 146.7 | 156 |
| kg/hr | 1,007 | 681 | 30.3 | 31.7 |
| g/kg sinter feed | 3.2 | 2.17 | - | - |
| Condensable Hydrocarbons, $mg/Nm^3$ | 7.0 | 6.4 | 4.2 | 4.25 |
| kg/hr | 6.0 | 4.0 | 0.92 | 0.85 |
| g/kg sinter feed | 0.019 | 0.013 | - | - |

NOTE 1: - Results of tests on flowrate processed through gravel bed system only.

TABLE NO. 10
NO RECYCLE TEST RESULTS - TEST MODE #1

| TEST DATE | 8/ 3/77 | 8/ 4/77 | 8/ 9/77 | 8/11/77 | 8/30/77 | 9/20/77 | 9/23/77 | 9/28/77 | 10/1/77 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| Stack Effluent Flow | | | | | | | | | | |
| $Nm^3/min$ | 14,287 | 13,995 | 14,318 | 14,882 | 14,201 | 13,222 | 15,312 | 14,218 | 13,728 | 14,240 |
| (dscfm) | (504,834) | (494,556) | (505,952) | (525,878) | (501820 ) | (467,184) | (541,093) | (502,372) | (485,083) | (503,197) |
| Temp. $^oC.(^oF.)$ | 134(274) | 109(228) | 110(231) | 135 (276) | 98(208) | 101(214) | 133 (272) | 101(214) | 110(231) | 115(239) |
| Particulate | | | | | | | | | | |
| $mg/Nm^3$ | 1,657 | 999 | 980 | 756 | 1,282 | 1,523 | 989 | 1,324 | 1,128 | 1,182 |
| (grains/dscf) | ( 0.723) | ( 0.436) | ( 0.428) | ( 0.330) | ( 0.56 ) | ( 0.666) | ( 0.432) | ( 0.578) | ( 0.493) | ( 0.515) |
| kg/hr | 1,421 | 839 | 843 | 676 | 1,094 | 1,212 | 911 | 1,132 | 932 | 1,007 |
| (lb/hr) | ( 3,129) | ( 1,848) | ( 1,856) | ( 1,487) | ( 2,408) | ( 2,666) | ( 2,005) | ( 2,490) | ( 2,050) | ( 2,215) |
| Sulfur Dioxide | | | | | | | | | | |
| $mg/Nm^3$ | 231 | 398 | 49.3* | - | 415 | 263 | 197 | 527 | 206 | 320 |
| (grains/dscf) | ( 0.101) | ( 0.174) | ( 0.022) | - | ( 0.181) | ( 0.115) | ( 0.086) | ( 0.230) | ( 0.09 ) | ( 0.140) |
| kg/hr | 199 | 336 | 42.4* | - | 354 | 209 | 181 | 451 | 170 | 271 |
| (lbs/hr) | ( 437) | ( 737) | ( 93.3) | - | ( 779) | ( 460) | ( 399) | ( 991) | ( 375) | ( 597) |
| Hydrocarbons | | | | | | | | | | |
| Charge - kg/hr | 93 | 155 | 124 | 103 | 129 | 111 | 107 | 264* | 47.8* | 117 |
| (lbs/hr) | ( 205) | ( 341) | ( 272) | ( 227) | ( 283) | ( 244) | ( 236) | ( 580) | ( 105.2) | ( 258) |
| Product- Kg/hr | 10 | 38* | 5.4 | 6.5 | 6.0 | 9.5 | 10.4 | 9.2 | 4.8 | 7.7 |
| (lbs/hr) | ( 22) | ( 84) | ( 11.9) | ( 14.4) | ( 13.2) | ( 20.5) | ( 22.8) | ( 20.2) | ( 10.5) | ( 17 ) |
| Stack Gas $mg/Nm^3$ | 4.1 | 7.0 | 6.8 | 8.3 | 8.7 | 10.0 | 5.0 | 4.8 | 8.0 | 7.0 |
| (grains/dscf) | ( .0018) | ( .003) | ( .003) | ( .0036) | ( .0038) | ( .0044) | ( .0022) | ( .0021) | ( .0035) | ( .0031) |
| kg/hr | 3.5 | 6.0 | 5.8 | 7.5 | 7.5 | 7.9 | 4.6 | 4.0 | 6.9 | 6.0 |
| (lbs/hr) | ( 7.8) | ( 13.1) | ( 12.8) | ( 16.4) | ( 16.4) | ( 17.5) | ( 10.2) | ( 8.8 | ( 15.1) | ( 13.1) |

* - Data not used to obtain average since they don't fall within a normal distribution of values

TABLE NO. 11
RECYCLE TEST RESULTS - TEST MODE #2

| TEST DATE | 8/ 3/77 | 8/ 4/77 | 8/ 9/77 | 8/11/ 77 | 8/30/77 | 9/20/77 | 9/23/77 | 9/28/77 | 10/1/77 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| **Stack Effluent Flow** | | | | | | | | | | |
| $Nm^3/min$ | 11,864 | 10,851 | 9,606 | 10,742 | 10,851 | 9,534 | 10,535 | 9,915 | 10,608 | 10,330 |
| (dscfm) | (419,233)* | (383,435) | (339,436) | (379,588) | (383,430) | (336,900) | (372,246) | (350,336) | (374,828) | (365,025) |
| Temp. °C.(°F.) | 128 (263) | 115 (240) | 136 (278) | 130 (266) | 111 (231) | 117.8(244) | 122 (251) | 111 (232) | 105 (221) | 118.4(245) |
| Recycle % | 18.8* | 21.2 | 25.0 | 22.8 | 22.8 | 28.6 | 25.5 | 27.7 | 26.4 | 25 |
| **Particulates** | | | | | | | | | | |
| $mg/Nm^3$ | 3,256 | 1,390 | 994 | 723 | 1,020 | 887 | 1,168 | 1,266 | 1,301 | 1,094 |
| (grains/dscf) | ( 1,422)* | ( 0.607) | ( 0.434) | ( 0.316) | ( 0.445) | ( 0.387) | ( 0.510) | ( 0.553) | ( 0.568) | ( 0.477) |
| kg/hr | 2,321 | 906 | 574 | 468 | 666 | 507 | 739 | 754 | 830 | 681 |
| (lbs/hr) | ( 5,110)* | ( 1,995) | ( 1,263) | ( 1,028) | ( 1,462) | ( 1,117) | ( 1,627) | ( 1,661) | ( 1,828) | ( 1,498) |
| **Sulfur Dioxide** | | | | | | | | | | |
| $mg/Nm^3$ | 313 | 411 | 15.7 | - | 380 | 227 | 417 | 530 | 183 | 350 |
| (grains/dscf) | ( 0.137) | ( 0.179) | ( .0068)* | - | ( 0.166) | ( 0.095) | ( 0.182) | ( 0.232) | ( 0.080) | ( 0.153) |
| kg/hr | 225 | 267 | 9.1 | - | 248 | 124.6 | 264 | 317 | 16.7 | 223 |
| (lbs/hr) | ( 492) | ( 588) | ( 19.9) | - | ( 545) | ( 274) | ( 581) | ( 697) | ( 257) | ( 491) |
| **Hydrocarbons** | | | | | | | | | | |
| Charge - kg/hr | 313 | 311 | 266 | 79 | 19 | 98 | 144 | 194 | 80.2 | 119 |
| (lbs/hr) | ( 688)* | ( 684)* | ( 585)* | ( 174) | ( 261) | ( 216) | ( 317) | ( 427) | ( 176.5) | ( 262) |
| Product - kg/hr | 62 | 64.5 | 81.6 | 6.5 | 5.0 | 9.7 | 10.4 | 7.7 | 6.3 | 7.6 |
| (lbs/hr) | ( 137)* | ( 142)* | ( 180)* | ( 14.4) | ( 11.0) | ( 21.3) | ( 22.8) | ( 17) | ( 13.9) | ( 16.7) |
| Stack Gas-$Mg/Nm^3$ | 7.6 | 5.0 | 4.0 | 8.0 | 5.8 | 5.1 | 6.7 | 5.7 | 9.5 | 6.4 |
| (grains/dscf) | ( .0033) | ( .0022) | ( .0017) | ( .0035) | ( .0025 ) | ( .0022) | ( .0029) | ( .0025) | ( .0041) | ( .0028) |
| kg/hr | 5.4 | 3.3 | 2.3 | 5.1 | 3.7 | 3.0 | 4.3 | 3.3 | 6.0 | 4.0 |
| (lbs/hr) | ( 11.9) | ( 7.2) | ( 5.2) | ( 11.2) | ( 8.0) | ( 6.5 ) | ( 9.5) | ( 7.3) | ( 13.2) | ( 8.9) |

* - Data not used to obtain average since they don't fall within a normal distribution of values

TABLE NO. 12
GRAVEL BED FILTER TEST RESULTS - NO RECYCLE - TEST MODE #3

| TEST DATE | 7/18/78 | 7/19/78 | 7/21/78 | 7/27/78 | 7/28/78 | Average |
|---|---|---|---|---|---|---|
| % Recycle | 0 | 0 | 0 | 0 | 0 | 0 |
| Gas Flow | | | | | | |
| (A) Inlet, $Nm^3$/min | 1,996 | 2,885 | 2,101 | 3,106 | 2.758 | 2,569 |
| (dscfm) | ( 70,496) | (101,875) | ( 74,192) | (109,774) | ( 97,383) | ( 90,744) |
| °C.(°F.) | 104 (220) | 103.4 (218) | 94 (201) | 112.3 (234) | 127.9 (262) | 108.3 (227) |
| (B) Stack, $Nm^3$/min | 3,292 | 2,947 | 2,362 | 3,833 | 4,122 | 3,309 |
| (dscfm) | (116,206) | (103,699) | ( 83,406) | (135,409) | (145,550) | (116,854) |
| °C. (°F.) | 89 (192) | 91.2 (196) | 79 (174) | 94 (201) | 105 (221) | 91.6 (196.8) |
| Particulates | | | | | | |
| (A) Inlet mg/$Nm^3$ | 1,705 | 1,352 | 1,746 | 922 | 771 | 1,299 |
| (grains/dscf) | ( 0.745) | ( 0.591) | ( 0.763) | ( 0.403) | ( 0.337) | ( 0.568) |
| kg/hr (lbs/hr) | 204.4 (450) | 241 (530) | 226 (418) | 177.1 (390) | 131.2 (289) | 195.9 (431.4) |
| (B) Stack mg/$Nm^3$ | 153.2 | 157.o | 119.4 | 149 | 155 | 146.7 |
| (grains/dscf) | ( 0.0669) | ( 0.0686) | ( 0.0521) | ( 0.0649) | ( 0.0675) | ( 0.064) |
| kg/hr (lbs/hr) | 31 (68.4) | 28.5 (62.7) | 17.4 (38.3) | 35.1 (77.4) | 39.3 (86.5) | 30.3 (66.7) |
| Sulfur Dioxide | | | | | | |
| (A) Inlet mg/$Nm^3$ | 9.7* | 72.6 | 177 | 325.7 | 75.9 | 175.2 |
| (grains/dscf) | ( 0.004)* | ( 0.0317) | ( 0.077) | ( 0.142) | ( 0.0331) | ( 0.076) |
| kg/hr (lbs/hr) | 1.09 (2.4)* | 12.6 (27.7) | 22.2 (49) | 60.7 (133.6) | 12.5 (27.6) | 27.0 (59.5) |
| (B) Stack mg/$Nm^3$ | 292.6 | 261 | 229 | 339 | 100.0 | 244.3 |
| (grains/dscf) | ( 0.128) | ( 0.0848) | ( 0.10) | ( 0.148 ) | ( 0.0439) | ( 0.1) |
| kg/hr (lbs/hr) | 57.9 (127.5) | 34.2 (75.4) | 32.5 (71.5) | 78 (171.8) | 24.9 ( 54.8) | 45.5 (100.2) |
| **Hydrocarbns | | | | | | |
| (A) Inlet mg/$Nm^3$ | 14.1 | 0.121 | 5.65 | 17.6 | 2.48 | 7.99 |
| (grains/dscf) | ( 0.0062) | ( 0.00005) | ( 0.00247) | ( 0.0077) | ( 0.0011) | ( 0.0035) |
| Kg/hr (lbs/hr) | 1.8 (4.0) | 0.034 (0.075) | 0.73 (1.61) | 3.38 (7.44) | 0.42 (0.93) | 1.27 (2.81) |
| (B) Stack mg/$Nm^3$ | 0.188 | 1.0 | 3.87 | 13.9 | 2.08 | 4.2 |
| (grains/dscf) | ( 0.000082) | ( 0.00043) | ( 0.00169) | ( 0.0061) | ( .00091) | ( 0.0018) |
| kg/hr (lbs/hr) | 0.039 (0.086) | 0.18 (0.4) | 0.57 (1.24) | 3.27 (7.2) | 0.53 (1.16) | 0.92 (2.02) |

* - Data not used to obtain average since they don't fall within a normal distribution of values
** - Back half only

TABLE NO. 13

GRAVEL BED FILTER TEST RESULTS - RECYCLE - TEST MODE #4

| TEST DATE | 7/18/78 | 7/19/78 | 7/21/78 | 7/27/78 | 7/28/78 | Average |
|---|---|---|---|---|---|---|
| % Recycle | 21.2 | 31.9 | 17.3 | 27.1 | 26.4 | 24.8 |
| Gas Flow | | | | | | |
| (A) Inlet $Nm^3/min$ | 1,754 | 2,784 | 1,984 | 2,760 | 2,811 | 2.419 |
| (dscfm) | ( 61,737 | ( 98,313) | ( 70,046) | ( 97,534) | ( 99,255) | ( 85,377) |
| °C.(°F.) | 114 (237) | 95.6 (204) | 105.6 (222) | 118.4 (245) | 118.4 (245) | 110.4 (230.6) |
| (B) Stack $Nm^3/min$ | 2,847 | 2,851 | 2,198 | 3,710 | 3,875 | 3,096 |
| (dscfm) | (100,535) | (100,677) | ( 77,626) | (131,119) | (136,818) | (109,355) |
| °C.(°F.) | 98.4 (209) | 94 (201) | 90 (194) | 100.6 (213) | 109.5 (229) | 98.5 (209.2) |
| Particulates | | | | | | |
| (A) Inlet $mg/Nm^3$ | 1,664 | 1,834 | 1,037 | 1,806 | 1,482 | 1,565 |
| (grains/dscf) | ( 0.727) | ( 0.801) | ( 0.453) | ( 0.789) | ( 0.648) | ( 0.6836) |
| kg/hr (lbs/hr) | 174.7(385) | 315 (693) | 126.7 (279) | 307.9 (678) | 249.3 (549) | 234.7 (517) |
| (B) Stack $Mg/Nm^3$ | 134.4 | 85.8 | 111.5 | 245 | 204 | 156 |
| (grains/dscf) | ( 0.0587) | ( 0.0374) | ( 0.0487) | ( 0.107) | ( 0.0889) | ( 0.068) |
| kg/hr (lbs/hr) | 23.6 (51.9) | 15.1 (33.2) | 15.1 (33.3) | 55.9 (123) | 48.6 (107) | 31.7 (69.7) |
| Sulfur Dioxide | | | | | | |
| (A) Inlet $mg/Nm^3$ | 267 | 93.5 | 412 | 366.4 | 145.5 | 257 |
| (grains/dscf) | ( 0.116) | ( 0.0408) | ( 0.180) | ( 0.160) | ( 0.0635) | ( 0.112) |
| kg/hr( lbs/hr) | 27.9 (61.4) | 15.6 (34.4) | 49 (108) | 60.7 (133.8) | 24.5 (54) | 35.5 (78.3) |
| (B) Stack $mg/Nm^3$ | 218.9 | 373 | 416 | 11.6* | 2.78* | 280.5 |
| (grains/dscf) | ( 0.0956) | ( 0.163) | ( 0.182) | ( 0.0051)* | ( 0.00121)* | ( 0.122) |
| kg/hr (lbs/hr) | 37.4 (82.4) | 63.9 (140.7) | 55 (121.1) | 2.6 (5.73)* | 0.64 (1.4) * | 52.1 (1146) |
| **Hydrocarbons-Condensible | | | | | | |
| (A) Inlet $mg/Nm^3$ | 14.3 | 3.16 | 5.82 | 15.2 | 1.24 | 7.9 |
| (grains/dscf) | ( 0.0063) | ( 0.0014) | ( 0.00254) | ( 0.0062) | ( 0.00054) | ( 0.0034) |
| kg/hr (lbs/hr) | 1.6 (3.5) | 0.55 (1.2) | 0.71 (1.57 | 2.6 (5.72) | 0.21 (0. 46) | 1.13 (2.49) |
| (B) Stack $mg/Nm^3$ | 0.286 | 6.98 | 3.22 | 8.7 | 2.05 | 4.25 |
| (grains/dscf) | ( 0.000125) | ( 0.00305) | ( 0.00171) | ( 0.0038) | ( 0.00089) | ( 0.0019) |
| kg/hr (lbs/hr) | 0.053 (0.116) | 1.2 (2.7) | 0.53 (1.17) | 2.0 (4.4) | 0.49 (1.08) | 0.85 (1.89) |

* - Data not used to obtain average since they don't fall within a normal distribution of values

** - Back Half Only

Section V-C - Environmental Aspects (cont'd)

Test Results (cont'd

Phase A Testing (Hydrocarbons)

Test Mode No. 1 - The condensable hydrocarbon emission rate under normal operation with no recycle was 7.0 mg/$Nm^3$(0.0031 grains/dscf). A volume of 14,240 $Nm^3$/min. (503,197 dscfm) produced a mass emission rate of 6.0 kg/hr (13.1 lbs/hr) or 0.019 g/kg (0.038 lbs/ton) of burden to the sinter machine (see Tables Nos. 9 and 10 for individual test results).

Test Mode No. 2 - With an average 25 percent recycle of waste gas it was determined that the waste gas contained a condensable hydrocarbon concentration of 6.4 mg/$Nm^3$ (0.0028 grains/dscf). With an average flow rate of 10,330 $Nm^3$/min. (365,025 dscfm) the mass emission rate was 4.0 kg/hr (8.9 lbs/hr) which is equivalent to 0.013 g/kg (0.026 lbs/ton) of sinter strand feed (see Tables Nos. 9 and 11 for individual results).

A comparison of the test results shows a reduction of thirty-two percent of condensable hydrocarbons discharged under recycle conditions.

Phase B Testing (Hydrocarbons)

Test Mode No. 3; No Recycle/Gravel Bed Filter Only - Tests conducted on the gravel bed inlet gas using the back-half of the Environmental Protection Agency method train produced hydrocarbon concentrations of 7.99 mg/$Nm^3$ (0.0035 grains/dscf). The calculated mass emission rate using a measured average flow rate of 2569 $Nm^3$/min. (90,744 dscfm) was 1.27 kg/hr (2.81 lbs/hr).

Stack gas concentrations determined simultaneously with the inlet were 4.2 mg/$Nm^3$ (0.0018 grains/dscf). An average stack flow of 3309 $Nm^3$/min. (116,854 dscfm) and the measured concentration produced a mass loading of 0.93 kg/hr (2.02 lbs/hr) of condensable hydrocarbons (see Table No. 12 for individual test results).

Although the deviation in individual data was extreme, the average result indicated a twenty-eight percent reduction of condensible hydrocarbons in the gravel bed filter system.

Section V-C - Environmental Aspects (cont'd)

Test Results (cont'd)

Phase B Testing (Hydrocarbons) (cont'd)

Test Mode No. 4; Recycle and Gravel Bed Operation - While maintaining an average twenty-five percent windbox gas recycle, samples of the gravel bed inlet were collected. Results indicate an average concentration of 7.9 mg/$Nm^3$ (0.0034 grains/dscf) and a mass emission rate of 1.13 kg/hr (2.49 lbs/hr) based on a flow rate of 2419 $Nm^3$/min (85,377 dscfm).

Stack samples taken concurrent with the inlet samples resulted in an average concentration of 4.25 mg/$Nm^3$ (0.0019 grains/dscf). Based on a flow rate of 3096 $Nm^3$/min. (109,55 dscfm) a mass hydrocarbon loading of 0.85 kg/hr (1.89 lbs/hr) was calculated (see Table No. 13 for individual test results).

The average data indicated a condensable hydrocarbon reduction of twenty-five percent in the gravel bed filter system, but as in the case of Mode No. 3, variation in individual results was excessive.

## TEST RESULTS DISCUSSION AND CONCLUSIONS

Phase A Testing (Test Modes Nos. 1 and 2) - An analysis of test results indicates that reductions of thirty-two percent particulate, eighteen percent sulfur dioxide and thirty-two percent condensable hydrocarbon mass emissions closely parallel the amount of recycled gas. No appreciable increase or decrease in concentrations of these parameters were noted. Some slight decrease, approximately seven percent, in particulate concentration was measured under recycle conditions. However, this is considered to be within the normal variation of stack sampling results for a Method 5 determination.

Hydrocarbon emission concentration data also indicated a reduction of approximately nine percent in the recycle operational mode. These results were somewhat disappointing in that a higher reduction was expected. Attempts to perform a material balance by analyzing feed and product samples during the test effort produced mixed results. Under recycle conditions only 9.8 percent of the condensable hydrocarbons present in the charge materials could be accounted for in the sinter product and waste gas with a 65.2 percent and 34.8 percent contribution respectively. With no recycle, 11.7 percent of the condensable hydrocarbons in the charge materials were present in the sinter product and waste gas components. The sinter product contained 57 percent and the waste gas 43 percent of the accountable hydrocarbons. This would indicate that under either mode of operation approximately 90 percent of the hydrocarbon charge rate was destroyed by the sintering process. However, there have been many questions

raised over the methods of analysis of condensable hydrocarbons and possible interferences in these procedures. Therefore, the data generated by this test program should be viewed with an air of caution until the "definitive method" is developed to analyze condensable hydrocarbons with some degree of confidence.

Sulfur dioxide concentrations with twenty-five percent recycle indicated a seventeen percent reduction. A slight increase in the waste gas sulfur dioxide concentration under recycle conditions was noted, approximately nine percent. This indicates some build-up of sulfur dioxide, however, net reductions with recycle are realized.

The test results obtained for this test period should represent sinter operations with a range of 2.4 to 3 basicity.

Phase B Testing (Test Modes Nos. 3 and 4)

An analyses of the data representing Test Mode No. 3 indicate an eighty-five percent decrease in particulate emissions, a sixty-eight percent increase in sulfur dioxide emissions and a twenty-eight percent decrease in condensable hydrocarbon emissions through the gravel bed filter system. Similarly, an analyses of the data for Test Mode No. 4 indicate an eighty-eight percent decrease in particulate emissions, a forty-seven percent increase in sulfur dioxide emissions, and a twenty-five percent decrease in condensable hydrocarbons.

In both modes of operation, the particulate concentration in the gravel bed filter effluent was approximately 150 $mg/Nm^3$ and the efficiency of the system was less than ninety percent. However, as stated previously in Section V-B of this report, the detrimental effects of the screen blinding problem on the operating reliability and performance of the gravel bed filter system cannot be over-emphasized. Under optimized conditions, the gravel bed filter system has demonstrated the capability of producing an effluent concentration of less than 70 $mg/Nm^3$ of particulate. During periods of malfunction with blinded screens, the effluent concentration is more than tripled.

Although the data for certain test runs were suspect, the increase in sulfur dioxide emissions from the gravel bed filter system was expected in that the backflush air for the filter modules was heated in a direct fired system utilizing coke-oven gas. This increase in emission rate is minor in magnitude, and is considered insignificant. However, a ninety

Section V-C - Environmental Aspects (cont'd)

Test Results Discussion and Conclustion (cont'd)

Phase B Testing (Test Modes Nos. 3 and 4) (cont'd)

percent reduction in these emissions will occur in 1980 when the Company's coke-oven gas desulfurization program is completed.

It is presumed that the twenty-five to twenty-eight percent reduction in condensable hydrocarbons occurs due to the deposition of this organic material on the filter media, support screens and sinter dust as the effluent gas cools below 120° C. (248° F.). The benefit of this condition is questionable since it could be contributing to the blinding problem documented in Section V-B of this report. In view of the questions concerning condensable hydrocarbon sampling and analysis procedures, and the inconsistencies in the data generated in the test program, it must again be emphasized that any judgements concerning this parameter must be made cautiously.

An analyses of the environmental capabilities of the combined windbox gas recirculation and gravel bed filter systems cannot be accurately documented until the systems are totally optimized. As stated in Section V-B, the Company is aggressively pursuing programs to reduce the total effluent volume from the sinter machine.

Section V-D - Energy Aspects

Windbox Gas Recirculation System

The replacement of two existing 1865 kw (2500 bhp) fans with two new 3357 kw (4500 bhp) fans is a major consideration in the analysis of the energy aspects of this system. The new fans were installed to accommodate (1) the increased capacity requirement due to the anticipated elevation in windbox gas temperature, and (2) the additional resistance of the new ductwork from the fans to the sinter machine hoods. The design calculations for the gas flows, temperatures and pressure drops at a 39 percent recirculation rate are documented in the Phase I Report (1).

Section V-D - Energy Aspects (cont'd)

Windbox Gas Recirculation System (cont'd)

In actual operating practice, the anticipated elevation in windbox gas temperature did not occur. The design calculations were based on a windbox gas temperature of 194° C. (382° F.) whereas a temperature averaging approximately 121° C. (249° F.) was documented after the system was optimized. This lower temperature was a result of an adjustment in the quantity of coke breeze in the sinter burden, which was necessitated by excessive sinter bed temperature. To alleviate the excessive bed temperature and associated operating and maintenance problems, the quantity of coke breeze in the burden was reduced by 7 percent. Thus, during actual operation, the temperature below the strand burden is essentially the same with or without recirculation.

During the demonstration period, tests were conducted to determine the actual pressure drops in the system for comparison with the calculated design pressure drops. It must be noted that the test data varied significantly as a result of the uncontrollable variations in the sintering process. The tests indicate that the total system pressure drop with a 39 percent recirculation rate is approximately 1473 mm w.c. (58 in. w.c.) or 15 percent higher than predicted in the Phase I Report. This contradicts what would be expected with the lower temperature waste gas. Further, investigations indicate that the losses in the ductwork are indeed less than calculated in the design. However, the pressure drop across the sinter bed is substantially higher than design calculation predictions. It is difficult to ascertain the reasons for this higher pressure drop due to the many variables involved. Numerous possibilities may be responsible, such as (1) the flow of the dirty recirculation gases through the bed; (2) the change in the sinter mix due to excessive temperatures; or (3) unknown changes in the mode of operation. Measurements of the pressure drop across the cyclones have varied both above and below the design prediction of 229 mm w.c. (9.0 in. w.c.).

Although the total system drop is higher than design calculations, the fans have ample capacity. As stated previously, the original fan curves were developed for a temperature of 194° C. (382° F) The lower gas temperature, which is encountered in actual operation, shifts the fan curve upward. It appears that the system pressure requirements are slightly below the new fan curve for the desired flow. The fans are controlled by maintaining a constant motor current and by throttling fan louvers. Therefore, the difference in pressure between the fan curve and actual system pressure is dissipated across the louvers. This results in an inefficient use of energy, however, some margin of reserve is required to accommodate the pressure variations in the system. A cursory review indicates the present margin of reserve at 10 to 15 percent. One series of pressure drop measurements exemplified the need for a margin of reserve when significantly higher losses were measured across the bed and cyclones than observed during previous tests.

Section V-D - Energy Aspects (cont'd)

Windbox Gas Recirculation System (cont'd)

Energy data for the Sinter Plant were tabulated from the Company's monthly energy reports for reference periods before and after the installation of the windbox gas recirculation system (see Table 14). As a result of the fan replacement, electrical power consumption increased 77 joules/m.t. of sinter or 54 percent from 143 joules/m.t. prior to recirculation to 220 joules /m.t. after recirculation. As expected, the coke-oven gas consumption remained constant before and after the installation. Coke breeze consumption decreased 146 joules/m.t. of sinter or 7 percent from 2146 joules/m.t. before recirculation to 2000 joules/m.t. after recirculation. As stated previously, this adjustment was necessary to eliminate the problems associated with overheating the sinter bed. The total energy consumption per unit of sinter production decreased 69 joules/m.t. or 3 percent from 2510 joules/m.t. prior to recirculation to 2441 joules/m.t. after recirculation. The decrease in the energy requirement can be attributed to the recovery of heat from the recirculated waste gas and the reduction in coke breeze consumption. These data can be very misleading if taken out of context. While it is true that the windbox gas recirculation permits the recovery of waste heat, the fact remains that an inexpensive source of energy (coke breeze) is being replaced by an expensive source of energy (electricity). It must be emphasized that the trade-off between decreased coke breeze consumption and increased electrical power consumption represents an extremely unfavorable economic balance, as indicated in Section V-E of this report.

TABLE 14

SINTER PLANT ENERGY CONSUMPTION

| | | Electricity | Coke Oven Gas | Coke Breeze | Total |
|---|---|---|---|---|---|
| Sinter Plant Energy Consumption per unit of Sinter Production Prior to the Installation of the Windbox Gas Recirculation and Gravel Bed Filter Systems. | joules/m.t.<br>(mmbtu/ton) | 143<br>(0.123) | 221<br>0.190) | 2146<br>(1.845) | 2510<br>(2.158) |
| Sinter Plant Energy Consumption per unit of Sinter Production after the Installation of the Windbox Gas Recirculation System. | joules/m.t.<br>(mmbtu/ton) | 220<br>(0.189) | 221<br>(0.190) | 2000<br>(1.720) | 2441<br>(2.099) |
| Pollution Control Energy Consumption per Unit of Sinter Production and Percent Change due to the Installation of the Windbox Gas Recirculation System. | joules/m.t.<br>(mmbtu/ton)<br>% Change | 77<br>(0.066)<br>54% | 0<br>0<br>0 | -146<br>(-0.125)<br>-7% | -69<br>(-0.059)<br>-3% |
| Projected Sinter Plant Energy Consumption per Unit of Sinter Production After the Installation of the Windbox Gas Recirculation and Gravel Bed Filter System. | joules/m.t.<br>(mmbtu/ton) | 266<br>(0.229) | 268<br>(0.230) | 2000<br>(1.720) | 2534<br>(2.179) |
| Projected Pollution Control Energy Consumption per Unit of Sinter Production and Percent Change Due to the Installation of the Gravel Bed Filter System. | joules/m.t.<br>(mmbtu/ton)<br>% Change | 46<br>(0.040)<br>32% | 47<br>(0.041)<br>21% | 0<br>0<br>0 | 93<br>(0.081)<br>4% |
| Projected Pollution Control Energy Consumption per Unit of Sinter Production and Percent Change due to the Combined Installation. | joules/m.t.<br>(mmbtu/ton)<br>% Change | 123<br>(0.106)<br>86% | 47<br>(0.041)<br>21% | -146<br>(-0.125)<br>( -7% ) | 24<br>(0.021)<br>1% |

## Section V-D - Energy Aspects (contd)

### Gravel Bed Filter

During the demonstration period the flux rate through the gravel bed filter system was well below the design of 36.6 cu.m./min./$m^2$ (120 acfm/$ft^2$) of filter area due to the limitations of the induced draft fan. This fan limited the filtration process to only 40 percent of the total sinter machine windbox volume, and forced an effluent bypass of 35 percent assuming a windbox recirculation rate of 25 percent. As described more fully in Section V-B2 of this report, revisions to the system are in progress which will permit the treatment of the effluent gases currently being bypassed.

Due to the higher volume of gas and the resulting additional pressure drop, a significant increase in electrical energy requirements will occur after the completion of this program. The existing 746 k.w. (1000 b.h.p.) fan with a capacity of 6780 $m^3$/min. (240,000 acfm) at 149° C. (300° F.) will be replaced by a 2013 k.w. (2700 b.h.p.) fan with a capacity of 900 $m^3$/min. (350,000 acfm) at 116° C. (240° F.). At that time, total electrical energy requirements, including auxiliary motors for backflush fans and hydraulic pumps will increase from 1100 k.w. (1475 b.h.p.) to 2368 k.w. (3175 b.h.p.). In addition to the increased electrical power consumption, coke oven gas will be utilized at a rate of 7.08 $m^3$/min. (250 c.f.m.) to heat the filter backflush air from ambient temperature to 149° C. (300° F.).

The projected Sinter Plant energy consumption at that time will increase 46 joules/m.t. or 21 percent for electricity and 47 joules/m.t. or 21 percent for coke-oven gas (see Table 14). The projected total Sinter Plant energy consumption will increase 93 joules/m.t. or 4 percent from 2441 joules/m.t. to 2534 joules/m.t. of sinter production.

### Combined Systems

Table 14 also projects the change in Sinter Plant energy consumption due to the combined windbox gas recirculation and gravel bed filter systems. This projection indicates an increase in electrical power consumption of 86 percent or 123 joules/m.t. of sinter production, an increase in coke oven gas consumption of 21 percent or 47 joules/m.t. of sinter production, and a decrease in coke breeze consumption of 7 percent or 146 joules/m.t. of sinter production. The projection also indicates that the total energy consumption will increase 1 percent or 24 joules/m.t. of sinter. Again, it must be emphasized that the trade-off between the decreased coke breeze consumption and the increased electrical power consumption presents an extremely unfavorable economic balance due to the relatively low cost of coke breeze and high cost of electricity.

## Section V-E - Capital and Operating Costs

### Windbox Gas Recirculation System

During the period from August 1, 1975 to September 30, 1977, provisions were made to record the operating and maintenance costs (labor, material, utilities and depreciation) for the Sinter Plant Windbox Gas Recirculation System. The boundaries of the system were identified to permit reliable cost documentation. In the case of labor costs, only maintenance and repair expenditures were accrued, since the addition of operating personnel was not required for this installation. Weirton Steel Division Sinter Plant personnel recorded the time and labor class required for the maintenance and repair of the system during the designated twenty-six month period. In addition, the cost of repair materials was also recorded.

Utility cost for the operation of the recirculation system was limited to electrical power consumption. It was necessary to prorate the electrical cost for fan operation since only a portion of the power consumed is attributed to recirculation of the gas. It was determined that the most appropriate method for prorating this cost would be based on the difference in electrical energy required for the sintering process before and after the recirculation system was installed. These requirements were 3728 kilowatts (5000 h.p.) before recirculation and 6711 kilowatts (9000 h.p.) after recirculation. Since the fan motors were fully loaded in both cases, it was concluded that the power consumed would be a calculated value based on this difference of 2983 kilowatts (4000 h.p.) and the actual operating hours of the system.

The capital cost for the windbox gas recirculation system was $5,334,000 when escalated to 1978 market conditions. Depreciation cost for the recirculation system was calculated utilizing this capital cost and an estimated useful life of eighteen years. The periodic straight-line depreciation method was used and it was assumed that the probable terminal salvage value for the equipment was negligible.

It was necessary to develop a credit for the 7 percent reduction in coke breeze consumption which occurred as a result of the optimization of the windbox gas recirculation system (see Section V-D concerning Energy Aspects). This credit was derived utilizing a coke breeze market price of $23.00/m.t. ($20.86 per ton).

A summary of the projected capital and operating costs for the windbox gas recirculation system is tabulated in Table 15. The operating cost for this facility averaged $864,000 per year which is equivalent to $0.79 per metric ton ($0.72 per short ton) of sinter produced.

TABLE 15

TABULATION OF CAPITAL AND OPERATING COSTS
FOR THE
SINTER PLANT WINDBOX GAS RECIRCULATION SYSTEM

A. Capital (1978 Dollars)* - $5,334,000

Life: - 18 Years

B. Actual operating costs based on data for the 26-month period from August 1, 1975 to September 30, 1977, escalated to 1978 dollars:

| Cost Description | Annual Operating Cost |
|---|---|
| Repair Labor | - $ 70,000 |
| Repair Material | - 96,000 |
| Electricity | - 560,000 |
| Depreciation | - 296,000 |
| Credit for Coke Breeze Reduction | - (158,000) |
| TOTAL | - $ 864,000 |
| **Annual Sinter Production** | |
| Metric Tons per Year | - 1,090,000 |
| (Short Tons per Year) | -(1,200,000) |
| **Cost per Unit of Sinter Production** | |
| Cost per Metric Ton | - $ 0.79 |
| (Cost per Short Ton) | -($ 0.72) |

* - Capital Costs Adjusted to 1978 Dollars Using ENGINEERING NEWS RECORD Index

## Gravel Bed Filter System

Although provisions were made to record the operating and maintenance costs for the gravel bed filter system during the demonstration period, utilization of these data would lead to serious inaccuracies in the analyses of pollution control economics for the system. As stated in previous sections of this report, fan limitations prevented the treatment of the total effluent volume from the sinter machine windbox gas recirculation system. In addition, the excessive downtime of the gravel bed filter system during the demonstration period made it impractical to perform an economic analyses on a basis of cost per unit of sinter produced. It was, therefore, concluded that a more accurate analyses could be accomplished utilizing actual material and labor costs expended during the demonstration period in combination with projected utility and capital costs for the revised system (see Section V-B; page 47).

The capital cost for the revised gravel bed filter system is $5,101,000 when equated to 1978 market conditions. Depreciation cost for the gravel bed filter system was calculated utilizing this capital cost and an estimated useful life of eighteen years. The periodic straight-line depreciation method was used and it was assumed that the probable terminal salvage value for the equipment was negligible. Costs for electrical power and coke oven gas consumption were derived utilizing design data.

A summary of the projected capital and operating costs for the gravel bed filter is tabulated in Table 16. The projected operating costs for the system is $1,198,000 per year which is equivalent to $1.10 per metric ton ($1.00 per short ton) of sinter produced.

## Combined Systems

Table 17 indicated the projected total capital and operating costs for the windbox gas recirculation and gravel bed filter systems. The total projected capital cost for the combined systems is $10,435,000 based on 1978 market conditions. The projected operating cost for the combined systems is $2,062,000 per year or $1.89 per metric ton ($1.72 per short ton) of sinter produced.

TABLE 16

TABULATION OF CAPITAL AND OPERATING COSTS
FOR THE
SINTER PLANT GRAVEL BED FILTER SYSTEM

A. Capital (1978 Dollars)* - $5,101,000

Life: - 18 Years

B. Projected Annual Operating Cost (1978 Dollars):

| Cost Description | | Annual Operating Cost |
|---|---|---|
| Repair Labor | - | $ 110,000 |
| Repair Material | - | 103,000 |
| Coke Oven Gas | - | 150,000 |
| Electricity | - | 552,000 |
| Depreciation | - | 283,000 |
| TOTAL | | $1,198,000 |

| Annual Sinter Production | |
|---|---|
| Metric Tons per Year | 1,090,000 |
| (Short Tons per Year) | (1,200,000) |

| Cost per Unit of Sinter Production | |
|---|---|
| Cost per Metric Ton | $ 1.10 |
| (Cost per Short Ton) | ($ 1.00) |

* - Capital Costs Adjusted to 1978 Dollars Using ENGINEERING NEWS RECORD Index

TABLE 17

TABULATION OF CAPITAL AND OPERATING COSTS
FOR THE COMBINED SINTER PLANT WINDBOX GAS
RECIRCULATION AND GRAVEL BED FILTER SYSTEMS

A. Capital (1978 Dollars) 10,435,000

Life: 18 Years

B. Projected Annual Operating Cost (1978 Dollars):

| Cost Description | | Annual Operating Cost |
|---|---|---|
| Repair Labor | - | $ 180,000 |
| Repair Material | - | 199,000 |
| Coke Oven Gas | - | 150,000 |
| Electricity | - | 1,112,000 |
| Depreciation | - | 579,000 |
| Credit for Coke Breeze Reduction | | (158,000) |
| TOTAL | | $2,062,000 |

Annual Sinter Production

| | |
|---|---|
| Metric Tons per Year | 1,090,000 |
| (Short Tons per Year) | (1,200,000) |

Cost per Unit of Sinter Production

| | |
|---|---|
| Cost per Metric Ton | $ 1.89 |
| (Cost per Short Ton) | ($ 1.72) |

## SECTION VI - REFERENCES


1 - Pengidore, D. A.,Sinter Plant Windbox Gas Recirculation Demonstration; Phase 1; Engineering and Design, Environmental Protection Technology Series, Publication No. E.P.A.-600/2-75-014, August, 1975. Available from National Technical Information Service (NTIS) Springfield, VA, as Report No. PB249-564/AS.

2 - Draft Method Determination of Particulate & Condensable Organic Emissions from Sinter Plants. To be published at a later date by the Environmental Protection Agency, Research Triangle Park, North Carolina.

3 - Method 1 - Sample and Velocity Traverses for Stationary Sources; Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate; FEDERAL REGISTER, Vol. 42, No. 160, August 18, 1977, p.p. 41755 to 41768.

4 - Method 5 - Determination of Patriculate Emissions from Stationary Sources; FEDERAL REGISTER, Vol. 42, No. 160, August 18, 1977, P.P. 41776 to 41782.

5 - Method 6 - Determination of Sulfur Dioxide Emissions from Staionary Sources; FEDERAL REGISTER, Vol. 42, No. 160, August 18, 1977, p.p. 41782 to 41784.

# SECTION VII

# APPENDICES

TABLE NO. 18

WINDBOX GAS RECYCLE SAMPLING

DATE: August 3, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 286 ( 315) | 286 ( 315) |
| (2) Product Rate | mt/h | (t/h) | 178 ( 195) | 178 ( 195) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 11,864 (419,233) | 14,287 (504,834) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 14,603 (516,006) | 14,287 (504,834) |
| (5) Percent Recycle | % | | 18.8 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 128 ( 263) | 134 ( 274) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 19,394 (684,826) | 25,016 (883,360) |
| (8) Stack Gas | % Oxygen | | 17.16 | 18.195 |
| | % Carbon Monoxide | | 0.595 | 0.555 |
| | % Carbon Dioxide | | 6.545 | 5.095 |
| | % Nitrogen | | 74.79 | 75.80 |
| (9) Moisture Percent | | | 11.8 | 7.0 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 3,256 ( 1,422) | 1,657 ( 0.723) |
| | kg/hr | (lbs/hr. ) | 2,321 ( 5,110) | 1,421 ( 3,129) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 313 ( 0.137) | 231 ( 0.101) |
| | kg/hr | (lbs/hr. .) | 224 ( 492 ) | 199 ( 437) |
| (12) Stack Gas Condensable Hydrocarbons | mg/$Nm^3$ | (grs/dscf) | 7.56 ( .0033) | 4.1 ( .0018) |
| | kg/hr. | (lbs/hr. .) | 5.4 ( 11.9 ) | 3.5 (7.8 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 313 ( 6.88) | 93 ( 205) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 62 ( 137) | 10 ( 22) |

TABLE NO. 19
WINDBOX GAS RECYCLE SAMPLING
DATE: August 4, 1978

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 339 ( 373) | 330 ( 383) |
| (2) Product Rate | mt/h | (t/h) | 197 ( 217) | 197 ( 217) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 10,851 (383,435) | 13,995 (494,556) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 13,776 (486,793) | 13,995 (494,556) |
| (5) Percent Recycle | % | | 21.2 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 115 ( 240) | 109 ( 228) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 16,995 (600,098) | 23,782 (839,748) |
| (8) Stack Gas | % Oxygen | | 15.88 | - |
| | % Carbon Monoxide | | 0.72 | - |
| | % Carbon Dioxide | | 7.14 | - |
| | % Nitrogen | | 76.26 | - |
| (9) Moisture Percent | | | 9.9 | 8.5 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 1,390 (0.607) | 999 (0.436) |
| | kg/hr | (lbs/hr. ) | 906 ( 1,995) | 839 ( 1,848) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 411 ( 0.179) | 398 (0.174 ) |
| | kg/hr | (lbs/hr. .) | 267 ( 588) | 335 ( 737 ) |
| (12) Stack Gas Condensable Hydrocarbons | mg./$Nm^3$ | (grs/dscf) | 5.02 ( .0022) | 7.0 ( .0031) |
| | kg/hr. | (lbs/hr. .) | 3.3 (7.2 ) | 6.0 (13.1 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 311 ( 684) | 155 ( 341) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 65 ( 142) | 38 ( 84) |

TABLE NO. 20
WINDBOX GAS RECYCLE SAMPLING

DATE: August 9, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 322 ( 354) | 322 ( 354) |
| (2) Product Rate | mt/h | (t/h) | 181 ( 199) | 181 ( 199) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 9,606 (339,436) | 14,318 (505,952) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 12,817 (452,885) | 14,318 (505,952) |
| (5) Percent Recycle | % | | 25.0 | 0 |
| (6) Stack Gas Temperature | $^oC.$ | ($^oF.$ ) | 136 ( 278) | 110 ( 231) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 16,323 (576,364) | 24,209 (854,826) |
| (8) Stack Gas | % Oxygen | | 16.1 | 17.1 |
| | % Carbon Monoxide | | 0.66 | 0.505 |
| | % Carbon Dioxide | | 6.18 | 4.735 |
| | % Nitrogen | | 77.0 | 77.7 |
| (9) Moisture Percent | | | 9.4 | 9.1 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 994 ( 0.434) | 980 ( 0.428) |
| | kg/hr | (lbs/hr. ) | 574 ( 1,263) | 844 ( 1,856 ) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 15.7 (0.00684) | 49.3 ( 0.022 ) |
| | kg/hr | (lbs/hr. .) | 9.9 ( 19.9) | 42.4 ( 93.3 ) |
| (12) Stack Gas Condensable Hydrocarbons | mg./$Nm^3$ | (grs/dscf) | 3.96 ( .0017 ) | 23.2 ( 0.003 ) |
| | kg/hr. | (lbs/hr. .) | 2.3 (5.2 ) | 5.8 ( 12.8 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 266 ( 585) | 124 ( 272 ) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 82 ( 180) | 5.4 ( 12 ) |

TABLE NO. 21

WINDBOX GAS RECYCLE SAMPLING

DATE: August 11, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 304 ( 334) | 304 ( 334) |
| (2) Product Rate | mt/h | (t/h) | 177 ( 195) | 177 ( 195) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 10,742 (379,588) | 14,882 (525,878) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 13,909 (491,522) | 14,882 (525,878) |
| (5) Percent Recycle | % | | 22.8 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 130 ( 266) | 135 ( 276) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 17,685 (624,467) | 25,865 (913,305) |
| (8) Stack Gas | % Oxygen | | 17.05 | 17.20 |
| | % Carbon Monoxide | | 0.575 | 0.63 |
| | % Carbon Dioxide | | 6.165 | 5.86 |
| | % Nitrogen | | 76.05 | 76.40 |
| (9) Moisture Percent | | | 10.2 | 9.6 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 723 ( 0.316) | 756 ( 0.330) |
| | kg/hr | (lbs/hr. ) | 468 ( 1,028) | 676 ( 1,488) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | - | - |
| | kg/hr | (lbs/hr. .) | - | - |
| (12) Stack Gas Condensable Hydrocarbons | mg/$Nm^3$ | (grs/dscf) | 8.0 ( .0035) | 8.3 ( .0036) |
| | kg/hr. | (lbs/hr. .) | 5.1 (11.2 ) | 7.5 (16.4 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 79 ( 174) | 103 ( 227) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 7 ( 14) | 7 ( 14) |

TABLE NO. 22
WINDBOX GAS RECYCLE SAMPLING
DATE: August 30, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 272 ( 300) | 272 ( 300) |
| (2) Product Rate | mt/h | (t/h) | 162 ( 178) | 162 ( 178) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 10,851 (383,430) | 14,201 (501,820) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 14,051 (496,497) | 14,201 (501,820) |
| (5) Percent Recycle | % | | 22.8 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 111 ( 231) | 98 ( 208) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 16,707 (589,911) | 23,634 (806,048) |
| (8) Stack Gas | % Oxygen | | 15.5 | 16.1 |
| | % Carbon Monoxide | | 0.72 | 0.68 |
| | % Carbon Dioxide | | 7.14 | 5.69 |
| | % Nitrogen | | 76.9 | 77.5 |
| (9) Moisture Percent | | | 8.2 | 9.4 |
| (10) Particulates | $mg/Nm^3$ | (grs./dscf) | 1,020 ( 0.445) | 1,282 ( 0.560) |
| | kg/hr | (lbs/hr. ) | 666 ( 1,462) | 1,094 ( 2,408) |
| (11) Sulfur Dioxide | $mg/Nm^3$ | (grs/dscf) | 380 ( 0.166) | 415 ( 0.181) |
| | kg/hr | (lbs/hr. .) | 249 ( 545) | 354 ( 779) |
| (12) Stack Gas Condensable Hydrocarbons | $mg/Nm^3$ | (grs/dscf) | 5.83 ( .0025) | 8.73 ( .0038) |
| | kg/hr. | (lbs/hr. .) | 3.7 ( 8.0 ) | 7.75 (16.4 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 119 ( 261) | 129 ( 283) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 5.0 (11.0 ) | 6.0 (13.2 ) |

TABLE NO. 23

WINDBOX GAS RECYCLE SAMPLING

DATE: September 20, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 314 ( 345) | 314 ( 345) |
| (2) Product Rate | mt/h | (t/h) | 190 ( 209) | 190 ( 209) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 9,534 (336,900) | 13,222 (467,184) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 13,391 (473,181) | 13,222 (467,184) |
| (5) Percent Recycle | % | | 28.8 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 118 ( 244) | 101 ( 214) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 13,830 (488,354) | 22,703 (801,665) |
| (8) Stack Gas | % Oxygen | | 20.96 | 20.96 |
| | % Carbon Monoxide | | 0.21 | 0.75 |
| | % Carbon Dioxide | | 0.75 | 0.21 |
| | % Nitrogen | | 78.08 | 78.08 |
| (9) Moisture Percent | | | 9.2 | 11.2 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 887 ( 0.387) | 1,528 ( 0.666) |
| | kg/hr | (lbs/hr. ) | 507 ( 1,117) | 1,212 ( 2,667) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf ) | 218 ( 0.095) | 263 ( 0.115) |
| | kg/hr | (lbs/hr. .) | 124.6 ( 274) | 209 ( 460) |
| (12) Stack Gas Condensable Hydrocarbons | mg./$Nm^3$ | (grs/dscf ) | 5.12( .0022) | 9.96 ( .0044) |
| | kg/hr. | (lbs/hr. .) | 3.0 ( 6.5 ) | 7.9 (17.5 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 98 ( 216) | 111 ( 244) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 9.7 (21.3 ) | 9.5 (20.9 ) |

TABLE NO. 24

WINDBOX GAS RECYCLE SAMPLING

DATE: September 23, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 329 ( 362) | 329 ( 362) |
| (2) Product Rate | mt/h | (t/h) | 199 ( 219) | 199 ( 219) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 10,535 (372,246) | 15,312 (541,093) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 14,134 (499,188) | 15,312 (541,093) |
| (5) Percent Recycle | % | | 25.5 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 122 ( 251) | 133 ( 272) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 16,996 (600,134) | 28,112 (992,638) |
| (8) Stack Gas | % Oxygen | | 14.73 | 16.30 |
| | % Carbon Monoxide | | 0.176 | 0.475 |
| | % Carbon Dioxide | | 8.26 | 5.80 |
| | % Nitrogen | | 76.83 | 77.43 |
| (9) Moisture Percent | | | 10.2 | 9.6 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 1,168 ( 0.510) | 989 ( 0.432) |
| | kg/hr | (lbs/hr. ) | 739 ( 1,627) | 911 ( 2,005) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 417 ( 0.182) | 197 ( 0.086) |
| | kg/hr | (lbs/hr..) | 264 ( 581) | 181 ( 399) |
| (12) Stack Gas Condensable Hydrocarbons | mg./$Nm^3$ | (grs/dscf) | 6.68 ( .0029) | 5.02 ( .0022) |
| | kg/hr. | (lbs/hr..) | 4.3 ( 9.5 ) | 4.6 (10.2 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 144 ( 317) | 107 ( 237) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 10.4 (22.8 ) | 10.4 (22.8 ) |

TABLE NO. 25

WINDBOX GAS RECYCLE SAMPLING

DATE: September 28, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 329 ( 362) | 329 ( 362) |
| (2) Product Rate | mt/h | (t/h) | 219 ( 241) | 219 ( 241) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 9,915 (350,336) | 14,218 (502,372) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 13,668 (482,965) | 14,218 (502,372) |
| (5) Percent Recycle | % | | 27.5 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 111 ( 232) | 101 ( 214) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 15,530 (548,404) | 24,050 (849,272) |
| (8) Stack Gas | % Oxygen | | 16.24 | 16.17 |
| | % Carbon Monoxide | | 0.77 | 0.78 |
| | % Carbon Dioxide | | 7.08 | 7.035 |
| | % Nitrogen | | 75.92 | 76.02 |
| (9) Moisture Percent | | | 8.9 | 7.9 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 1,266 ( 0.553) | 1,324 ( 0.578) |
| | kg/hr | (lbs/hr. ) | 754 ( 1,661) | 1,132 ( 2,490) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 530 ( 0.232) | 527 ( 0.230) |
| | kg/hr | (lbs/hr. .) | 317 ( 697) | 451 ( 991) |
| (12) Stack Gas Condensable Hydrocarbons | mg/$Nm^3$ | (grs/dscf) | 5.69 ( .0025) | 4.81 ( .0021) |
| | kg/hr. | (lbs/hr. .) | 3.3 ( 7.3 ) | 4.0 ( 8.8 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 194 ( 427) | 264 ( 580) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 7.7 (17 ) | 9.2 (20.2 ) |

TABLE NO. 26

WINDBOX GAS RECYCLE SAMPLING

DATE: October 1, 1977

| Parameter Measured | | | Recycle | No Recycle |
|---|---|---|---|---|
| (1) Charge Rate | mt/h | (t/h) | 328 ( 360) | 328 ( 360) |
| (2) Product Rate | mt/h | (t/h) | 171 ( 188) | 171 ( 188) |
| (3) Standard Stack Gas Flow | $Nm^3$/min. | (dscfm) | 10,608 (374,828) | 13,728 (485,083) |
| (4) Total Waste Gas Flow | $Nm^3$/min. | (dscfm) | 14,358 (507,360) | 13,728 (485,083) |
| (5) Percent Recycle | % | | 26.1 | 0 |
| (6) Stack Gas Temperature | $^oC$. | ($^oF$. ) | 105 ( 221) | 110 ( 231) |
| (7) Actual Stack Gas Flow | $m^3$/min. | (acfm) | 15,756 (556,322) | 23,306 (822,957) |
| (8) Stack Gas | % Oxygen | | 17.14 | 17.15 |
| | % Carbon Monoxide | | 0.75 | 0.725 |
| | % Carbon Dioxide | | 6.5 | 6.4 |
| | % Nitrogen | | 75.6 | 75.7 |
| (9) Moisture Percent | | | 9.3 | 8.4 |
| (10) Particulates | mg/$Nm^3$ | (grs./dscf) | 1,301 ( 0.568) | 1,128 ( 0.493) |
| | kg/hr | (lbs/hr. ) | 830 ( 1,825) | 932 ( 2,050) |
| (11) Sulfur Dioxide | mg/$Nm^3$ | (grs/dscf) | 183 ( 0.0799) | 206 ( 0.0900) |
| | kg/hr | (lbs/hr..) | 116.7 ( 257) | 170 ( 375) |
| (12) Stack Gas Condensable Hydrocarbons | mg./$Nm^3$ | (grs/dscf) | 9.54 ( .0041) | 7.95 ( 0.00335) |
| | kg/hr. | (lbs/hr..) | 6.0 (13.2 ) | 6.9 (15.1 ) |
| (13) Charge Condensable Hydrocarbons | kg/hr. | (lbs/hr. ) | 80.2 (176.5 ) | 47.8 (105.2 ) |
| (14) Product Condensable | kg/hr. | (lbs./hr.) | 6.3 (13.9 ) | 4.8 (10.5 ) |

TABLE NO. 27

VELOCITY MEASUREMENTS SUMMARY
RECYCLE FAN

| | DUCT DIAMETER 3.35 METERS | | |
|---|---|---|---|
| *Position (Meters) | High m/min | Low m/min | Average m/min |
| (0.058) S | 1248 | 1088 | 1159 |
| (0.183) S | 1309 | 1157 | 1210 |
| (0.323) S | 1309 | 1157 | 1216 |
| (0.493) S | 1309 | 1116 | 1203 |
| (0.686) S | 1309 | 1144 | 1210 |
| (0.973) S | 1367 | 1074 | 1210 |
| (1.778) N | 1338 | 1157 | 1223 |
| (2.057) N | 1367 | 1130 | 1248 |
| (2.261) N | 1423 | 1197 | 1273 |
| (2.413) N | 1476 | 1197 | 1315 |
| (2.565) N | 1476 | 1248 | 1350 |
| (2.692) N | 1528 | 1309 | 1444 |
| (0.058) E | 1581 | 1184 | 1384 |
| (0.183) E | 1627 | 1309 | 1444 |
| (0.323) E | 1578 | 1367 | 1455 |
| (0.483) E | 1528 | 1248 | 1439 |
| (0.686) E | 1476 | 1248 | 1401 |
| (0.973) E | 1476 | 1248 | 1355 |
| (1.778) W | 1476 | 1184 | 1321 |
| (2.057) W | 1367 | 1150 | 1284 |
| (2.261) W | 1476 | 1184 | 1291 |
| (2.413) W | 1423 | 1150 | 1266 |
| (2.565) W | 1367 | 1116 | 1260 |
| (2.692) W | 1367 | 1116 | 1229 |

* - Position indicates measurements from stack wall

TABLE NO. 28

VELOCITY MEASUREMENT SUMMARY
RECYCLE FAN

| | DUCT DIAMETER 3.35 METERS | | |
|---|---|---|---|
| *Position (Meters) | High m/min | Low m/min | Average m/min |
| (0.058) N | 2178 | 008 | 1572 |
| (0.183) N | 2100 | 1068 | 1650 |
| (0.323) N | 1980 | 1146 | 1644 |
| (0.483) N | 2358 | 1182 | 1644 |
| (0.686) N | 2358 | 1146 | 1608 |
| (0.973) N | 1764 | 1188 | 1494 |
| (1.778) S | 1566 | 990 | 1296 |
| (2.057) S | 1566 | 1032 | 1320 |
| (2.261) S | 1620 | 1008 | 1356 |
| (2.413) S | 1668 | 948 | 1380 |
| (2.565) S | 1620 | 906 | 1326 |
| (2.692) S | 1566 | 990 | 1254 |
| (0.058) W | 1812 | 990 | 1494 |
| (0.183) W | 1980 | 906 | 1602 |
| (0.323) W | 1900 | 906 | 1626 |
| (0.483) W | 2022 | 990 | 1590 |
| (0.686) W | 1812 | 990 | 1560 |
| (0.973) W | 1668 | 1068 | 1470 |
| (1.778) E | 1812 | 1146 | 1404 |
| (2.057) E | 1980 | 1110 | 1428 |
| (2.261) E | 1980 | 1146 | 1410 |
| (2.413) E | 1980 | 1248 | 1476 |
| (2.565) E | 1980 | 1146 | 1446 |
| (2.692) E | 1980 | 1110 | 1350 |

* - Position indicates measurement from stack wall

TABLE NO. 29

VELOCITY MEASUREMENTS SUMMARY
MACHINE RECYCLE

| | DUCT DIAMETER 3.35 METERS | | |
|---|---|---|---|
| *Position (Meters) | High m/min | Low m/min | Average m/min |
| (0.058) S | 666 | 486 | 570 |
| (0.183) S | 666 | 516 | 583 |
| (0.323) S | 709 | 486 | 608 |
| (0.483) S | 750 | 516 | 620 |
| (0.686) S | 709 | 516 | 620 |
| (0.973) S | 788 | 486 | 620 |
| (1.778) N | 709 | 455 | 596 |
| (2.057) N | 788 | 421 | 620 |
| (2.261) N | 788 | 486 | 620 |
| (2.413) N | 688 | 486 | 608 |
| (2.565) N | 750 | 455 | 608 |
| (2.692) N | 688 | 486 | 596 |
| (0.058) E | 688 | 544 | 596 |
| (0.183) E | 688 | 516 | 583 |
| (0.323) E | 709 | 544 | 620 |
| (0.483) E | 729 | 516 | 608 |
| (0.686) E | 769 | 455 | 620 |
| (0.973) E | 709 | 516 | 632 |
| (1.778) W | 750 | 486 | 632 |
| (2.057) W | 750 | 486 | 620 |
| (2.261) W | 769 | 516 | 620 |
| (2.413) W | 750 | 516 | 632 |
| (2.565) W | 750 | 421 | 596 |
| (2.692) W | 709 | 421 | 596 |

* - Position indicates measurements from stack wall

TABLE NO. 30
GRAVEL BED FILTER SAMPLING-INLET

DATE: July 18, 1978

| - Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 179 ( 197.0) | 179 ( 197.0) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 2,742 ( 96,827) | 2,667 ( 94,188) |
| @ Temperature | °C. | (°F. ) | 114 ( 237) | 104 ( 220) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 1,755 ( 61,737) | 1,996 ( 70,496) |
| Moisture | % Weight | | 16.2 | 4.0 |
| Molecular Weight | lbs/lb. mole | | 27.5 | 28.8 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,424 (685,845) | 19,424 (685,845) |
| @ Temperature | °C. | (°F.) | 114 ( 237) | 104 ( 220) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 12,380 (437,031) | 14,537 (513,174) |
| Moisture | % Weight | | 16.2 | 4.0 |
| Molecular Weight | lbs/lb. mole | | 27.5 | 28.8 |
| (4) Percent Recycle | % | | 21.2 | 0 |
| (5) Particulates (Filterable) | mg/$Nm^3$ | (grs/dscf) | 1,664 ( 0.727) | 1,705 ( 0.745) |
| | kg/hr. | (lbs/hr. ) | 174.7 ( 385) | 204.4 ( 450) |
| (6) Condensable Hydrocarbons Filter Fraction | mg/$Nm^3$ | (grs./dscf) | 15.3 ( 0.0067) | 13.5 ( 0.0059) |
| | kg/hr. | (lbs./hr. ) | 1.61( 3.55 ) | 1.82( 3.57 ) |
| Back-Half | mg/$Nm^3$ | (grs./dscf) | 14.3 ( .0063) | 14.1 ( .0062) |
| | kg/hr. | (lbs./hr. ) | 1.6 ( 3.50 ) | 1.8 ( 4.0 ) |
| (7) Sulfur Dioxide | mg./$Nm^3$ | (grs./dscf) | 267 ( 0.116) | 9.7 ( 0.004) |
| | kg/hr. | (lbs./hr. ) | 27 ( 61.4 ) | 1.09( 2.4 ) |

TABLE NO. 31
GRAVEL BED FILTER SAMPLING -INLET

DATE: July 19, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 182.7 ( 201) | 182.7 ( 201) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 3,857 (136,197) | 4,009 (141,568) |
| @ Temperature | °C. | (°F. ) | 95.6 ( 204) | 103.4( 218) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,784 ( 98,313) | 2,885 (101,875) |
| Moisture | % Weight | | 9.6 | 7.9 |
| Molecular Weight | lbs/lb. mole | | 28.2 | 28.4 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,146 (676,086) | 19,146 (676,086) |
| @ Temperature | °C. | (°F.) | 95.6 ( 204) | 103.4 ( 218) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 13,819 (487,841) | 13,789 (486,751) |
| Moisture | % Weight | | 9.6 | 7.9 |
| Molecular Weight | lbs/lb. mole | | 28.2 | 28.4 |
| (4) Percent Recycle | % | | 32.0 | 0 |
| (5) Particulates (Filterable) | mg/$Nm^3$ | (grs/dscf) | 1,834 ( 0.801) | 1,352 ( 0.591) |
| | kg/hr. | (lbs/hr. ) | 315 ( 693) | 241 ( 530) |
| (6) Condensable Hydrocarbons Filter Fraction | mg/$Nm^3$ | (grs./dscf) | 15.6 ( 0.0068) | 16 ( 0.007) |
| | kg/hr. | (lbs./hr. ) | 2.6 ( 5.73 | 2.78( 6.11 ) |
| Back-Half | mg/$Nm^3$ | (grs./dscf) | 3.16( 0.0014) | 0.121 ( 0.00005) |
| | kg/hr. | (lbs./hr. ) | 0.545( 1.2 ) | 0.034 ( .075 ) |
| (7) Sulfur Dioxide | mg/$Nm^3$ | (grs./dscf) | 93.5 ( 0.0408) | 72.6 ( 0.0317 ) |
| | kg/hr. | (lbs./hr. ) | 15.6 (34.4 ) | 12.6 (27.7 ) |

TABLE NO. 32
GRAVEL BED FILTER SAMPLING-INLET

DATE: July 21, 1978

| Parameter Measured | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|
| | | Recycle | No Recycle |
| (1) Sinter Product | mt/h (t/h) | 206 ( 227) | 206 ( 227) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. (acfm) | 2,895 (102,237) | 2,823 ( 99,670) |
| @ Temperature | °C. (°F. ) | 105.6 ( 222) | 94 ( 201) |
| @ Standard Cond. | $Nm^3$/min. (dscfm) | 1,984 ( 70,046) | 2,101 ( 74,192) |
| Moisture | % Weight | 11.9 | 7.1 |
| Molecular Weight | lbs/lb. mole | 27.9 | 28.2 |
| (3) Gas Flow-Total Windbox | $m^3$/min. (acfm) | 20,270 (715,747) | 20,270 (715,747) |
| @ Temperature | °C. (°F.) | 105.6 ( 222) | 94 ( 201) |
| @ Standard Cond. | $Nm^3$/min. (dscfm) | 13,882 (490,034) | 15,103 (533,150) |
| Moisture | % Weight | 11.9 | 7.1 |
| Molecular Weight | lbs/lb. mole | 27.9 | 28.2 |
| (4) Percent Recycle | % | 17.3 | 0 |
| (5) Particulates (Filterable) | $mg/Nm^3$ (grs/dscf) | 1,037 ( 0.453) | 1,746 ( 0.763) |
| | kg/hr. (lbs/hr. ) | 126.7 ( 279) | 226 ( 498) |
| (6) Condensable Hydrocarbons Filter Fraction | $mg/Nm^3$ (grs./dscf) | 10.1 ( 0.0044) | 40.7 ( 0.0178) |
| | kg/hr. (lbs./hr. ) | 1.2 ( 2.64 ) | 5.14(11.32 ) |
| Back-Half | $mg/Nm^3$ (grs./dscf) | 5.82( 0.0025) | 5.65( 0.00247) |
| | kg/hr. (lbs./hr. ) | 0.71( 1.57 ) | 0.73( 1.61 ) |
| (7) Sulfur Dioxide | $mg/Nm^3$ (grs./dscf) | 412 ( 0.180 ) | 177 ( 0.077 ) |
| | kg/hr. (lbs./hr. ) | 49 ( 108 ) | 22.2 ( 49) |

TABLE NO. 33
GRAVEL BED FILTER SAMPLING-INLET

DATE: July 27, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 176 ( 194) | 176 ( 194) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 4,046 (142,868) | 4,393 (155,122) |
| @ Temperature | °C. | (°F. ) | 118.3 ( 245) | 112.3 ( 234) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,760 ( 97,534) | 3,109 (109,774) |
| Moisture | % Weight | | 9.14 | 7.37 |
| Molecular Weight | lbs/lb. mole | | 28.49 | 28.69 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,110 (675,103) | 19,110 (675,103) |
| @ Temperature | °C. | (°F.) | 118.3 ( 245) | 112.3 ( 234) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 14,198 (501,397) | 13,537 (477,983) |
| Moisture | % Weight | | 9.14 | 7.37 |
| Molecular Weight | lbs/lb. mole | | 28.5 | 28.7 |
| (4) Percent Recycle | % | | 27.1 | 0 |
| (5) Particulates (Filterable) | mg/$Nm^3$ | (grs/dscf) | 1,806 ( 0.789) | 922 ( 0.403) |
| | kg/hr. | (lbs/hr. ) | 307.9 ( 678) | 177 ( 390) |
| (6) Condensable Hydrocarbons Filter Fraction | mg/$Nm^3$ | (grs./dscf) | - | - |
| | kg/hr. | (lbs./hr. ) | - | - |
| Back-Half | mg/$Nm^3$ | (grs./dscf) | 15.2 ( 0.0062) | 17.6 ( 0.0137) |
| | kg/hr. | (lbs./hr. ) | 2.6 ( 5.72 ) | 3.38( 7.44 ) |
| (7) Sulfur Dioxide | mg/$Nm^3$ | (grs./dscf) | 366.4 ( 0.160 ) | 325.7 ( 0.142 ) |
| | kg/hr. | (lbs./hr. ) | 60.7 (133.8 ) | 60.7 (133.6 ) |

TABLE NO. 34
GRAVEL BED FILTER SAMPLING- INLET

DATE: July 28, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 194 ( 213.5) | 194 ( 213.5) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 4,119 (145,442) | 4,083 (144,173) |
| @ Temperature | °C. | (°F. ) | 118.3 ( 245) | 127.9 ( 262) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,811 ( 99,255) | 2,758 ( 97,393) |
| Moisture | % Weight | | 9.3 | 8.0 |
| Molecular Weight | lbs/lb. mole | | 28.4 | 28.6 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,682 (694,971) | 19,682 (694,971) |
| @ Temperature | °C. | (°F.) | 118.3 ( 245) | 127.8 ( 262) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 13,424 (473,871) | 13,297 (469,345) |
| Moisture | % Weight | | 9.3 | 8.0 |
| Molecular Weight | lbs/lb. mole | | 28.4 | 28.6 |
| (4) Percent Recycle | % | | 26.4 | 0 |
| (5) Particulates (Filterable) | mg/$Nm^3$ | (grs/dscf) | 1,482 ( 0.648) | 771 ( 0.337) |
| | kg/hr. | (lbs/hr. ) | 249.3 ( 549) | 131.2 ( 289) |
| (6) Condensable Hydrocarbons Filter Fraction | mg/$Nm^3$ | (grs./dscf) | 7.6 ( 0.0033) | 5.5 ( 0.0024) |
| | kg/hr. | (lbs./hr. ) | 1.28 ( 2.81 ) | 0.91( 2.0 ) |
| Back-Half | mg/$Nm^3$ | (grs./dscf) | 1.24 (0.00054) | 2.48( 0.0011) |
| | kg/hr. | (lbs./hr. ) | 0.21 (0.46 ) | 0.42( 0.93 ) |
| (7) Sulfur Dioxide | mg/$Nm^3$ | (grs./dscf) | 145.5 (0.0635 ) | 75.9 ( 0.0331) |
| | kg/hr. | (lbs./hr. ) | 24.5 ( 54) | 12.5 (27.6 ) |

TABLE NO. 35

GRAVEL BED FILTER SAMPLING - STACK

DATE: July 18, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 179 ( 197) | 179 ( 197) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 3,937 (139,011) | 3,291 (152,011) |
| @ Temperature | °C. | (°F. ) | 98.4 ( 209) | 89 ( 192) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,847 (100,535) | 3,292 (116,206) |
| Moisture | % Weight | | 8.67 | 5.9 |
| Molecular Weight | lbs/lb. mole | | 28.35 | 28.48 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,424 (685,845) | 19,424 (685,845) |
| @ Temperature | °C. | (°F.) | 98.4 ( 209) | 89 ( 192) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 14,058 (496,237) | 14,861 (524,619) |
| Moisture | % Weight | | 8.67 | 5.9 |
| Molecular Weight | lbs/lb. mole | | 28.35 | 28.48 |
| (4) Percent Recycle | % | | 21.2 | 0 |
| (5) Particulates (Filterable) | $mg/Nm^3$ | (grs/dscf) | 134.4 ( 0.0587) | 153.2 ( 0.0669) |
| | kg/hr. | (lbs/hr. ) | 23.6 ( 51.9 ) | 31 (68.4 ) |
| (6) Condensable Hydrocarbons Filter Fraction | $mg/Nm^3$ | (grs./dscf) | 1.35(0.00059) | 0.53( 0.00023) |
| | kg/hr. | (lbs./hr. ) | 0.23(0.51 ) | 0.10( 0.23 ) |
| Back-Half | $mg/Nm^3$ | (grs./dscf) | 0.286($1.25 \times 10^{-4}$) | 0.0188($0.82 \times 10^{-4}$) |
| | kg/hr. | (lbs./hr. ) | 0.053(0.116 ) | 0.039 (0.086 ) |
| (7) Sulfur Dioxide | $mg/Nm^3$ | (grs./dscf) | 218.9 ( .0956) | 292.6 (0.128 ) |
| | kg/hr. | (lbs./hr. ) | 37.4 (82.4 ) | 57.9 (127.5 ) |

TABLE NO. 36
GRAVEL BED FILTER SAMPLING - STACK

DATE: July 19, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 182.7 ( 201) | 182.7 ( 201) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 3,838 (135,521) | 3,935 (138,936) |
| @ Temperature | °C. | (°F. ) | 94 ( 201) | 91.2 ( 196) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,851 (100,677) | 2,937 (103,699) |
| Moisture | % Weight | | 7.4 | 7.7 |
| Molecular Weight | lbs/lb. mole | | 28.5 | 28.3 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,146 (676,086) | 19,146 (676,086) |
| @ Temperature | °C. | (°F.) | 94 ( 201) | 91.2 ( 196) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 14,221 (501,981) | 14,282 (504,168) |
| Moisture | % Weight | | 7.4 | 7.7 |
| Molecular Weight | lbs/lb. mole | | 28.5 | 29.3 |
| (4) Percent Recycle | % | | 32.0 | 0 |
| (5) Particulates (Filterable) | $mg/Nm^3$ | (grs/dscf) | 85.8 ( 0.0374) | 157.1 ( 0.0686) |
| | kg/hr. | (lbs/hr. ) | 15.1 ( 33.2 ) | 28.5 ( 62.7 ) |
| (6) Condensable Hydrocarbons Filter Fraction | $mg/Nm^3$ | (grs./dscf) | 0.25 (0.00011) | 157.1 ( 0.0686) |
| | kg/hr. | (lbs./hr. ) | 15.1 (33.2 ) | 28.5 ( 62.7 ) |
| Back-Half | $mg/Nm^3$ | (grs./dscf) | 6.98 (0.00305) | 1.0 (0.00043 ) |
| | kg/hr. | (lbs./hr. ) | 1.2 (2.7 ) | 0.18(0.4 ) |
| (7) Sulfur Dioxide | $mg/Nm^3$ | (grs./dscf) | 373 ( 0.0163) | 261 ( 0.0848) |
| | kg/hr. | (lbs./hr. ) | 63.9 (140.7 ) | 34.2 ( 75.4 ) |

TABLE NO. 37
GRAVEL BED FILTER SAMPLING - STACK

DATE: July 21, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 206 ( 227) | 206 ( 227) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 3,027 (106,885) | 3,140 (110,858) |
| @ Temperature | °C. | (°F. ) | 90 ( 194) | 79 ( 174) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 2,198 ( 77,626) | 2,362 ( 83,406) |
| Moisture | % Weight | | 10.3 | 9.4 |
| Molecular Weight | lbs/lb. mole | | 28.1 | 27.9 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 20,270 (715,747) | 20,270 (715,747) |
| @ Temperature | °C. | (°F.) | 90 ( 194) | 79 ( 174) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 14,739 (520,296) | 15,357 (542,093) |
| Moisture | % Weight | | 10.3 | 9.4 |
| Molecular Weight | lbs/lb. mole | | 28.1 | 27.9 |
| (4) Percent Recycle | % | | 17.3 | 0 |
| (5) Particulates (Filterable) | $mg/Nm^3$ | (grs/dscf) | 111.5 ( 0.0487) | 119.4 ( 0.0521) |
| | kg/hr. | (lbs/hr. ) | 15.1 ( 33.3 ) | 17.4 ( 38.3 ) |
| (6) Condensable Hydrocarbons Filter Fraction | $mg/Nm^3$ | (grs./dscf) | 0.62 (0.00027) | No Sample |
| | kg/hr. | (lbs./hr. ) | 0.08 (0.18 ) | - |
| Back-Half | $mg/Nm^3$ | (grs./dscf) | 3.22 (0.00171) | 3.87 (0.00169) |
| | kg/hr. | (lbs./hr. ) | 0.53 (1.17 ) | 0.56 (1.24 ) |
| (7) Sulfur Dioxide | $mg/Nm^3$ | (grs./dscf) | 416 ( 0.182) | 229 ( 0.10 ) |
| | kg/hr. | (lbs./hr. ) | 55 ( 121) | 32.5 ( 71.5 ) |

TABLE NO. 38

GRAVEL BED FILTER SAMPLING - STACK

DATE: July 27, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 176 ( 194) | 176 ( 194) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 5,110 (180,445) | 5,053 (178,431) |
| @ Temperature | °C. | (°F. ) | 100.6 ( 213) | 94 ( 201) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 3,710 (131,119) | 3,833 (135,409) |
| Moisture | % Weight | | 7.8 | 5.4 |
| Molecular Weight | lbs/lb. mole | | 28.6 | 28.8 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | | |
| @ Temperature | °C. | (°F.) | 19,110 (675,103) | 19,110 (675,103) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 100.6 ( 213) | 94 ( 201) |
| Moisture | % Weight | | 14,198 (501,397) | 13,537 (477,982) |
| Molecular Weight | lbs/lb. mole | | 7.7 | 5.36 |
| (4) Percent Recycle | % | | 28.55 | 28.82 |
| (5) Particulates (Filterable) | | | 27.1 | 0 |
| | $mg/Nm^3$ | (grs/dscf) | 245 ( 0.107) | 149 ( 0.0649) |
| | kg/hr. | (lbs/hr. ) | 55.9 ( 123) | 35.1 ( 77.4 ) |
| (6) Condensable Hydrocarbons Filter Fraction | $mg/Nm^3$ | (grs./dscf) | 8.7 ( 0.0038) | 13.9 ( 0.0061) |
| | kg/hr. | (lbs./hr. ) | 2.0 | 3.27( 7.2 ) |
| Back-Half | $mg/Nm^3$ | (grs./dscf) | No Sample | No Sample |
| | kg/hr. | (lbs./hr. ) | | |
| (7) Sulfur Dioxide | $mg/Nm^3$ | (grs./dscf) | 11.6 ( 0.0051) | 339 ( 0.148 ) |
| | kg/hr. | (lbs./hr. ) | 2.6 ( 5.73 ) | 78 (171.8 ) |

TABLE NO. 39
GRAVEL BED FILTER SAMPLING-STACK

DATE: July 28, 1978

| Parameter Measured | | | OPERATIONAL MODE-MAIN WINDBOX GAS | |
|---|---|---|---|---|
| | | | Recycle | No Recycle |
| (1) Sinter Product | mt/h | (t/h) | 194 ( 213.5) | 194 ( 213.5) |
| (2) Gas Flow to Gravel Bed | $m^3$/min. | (acfm) | 5,474 (193,303) | 5,620 (198,466) |
| @ Temperature | °C. | (°F. ) | 109.4( 229) | 105 ( 221) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 3,875 (136,818) | 4,122 (145,550) |
| Moisture | % Weight | | 8.0 | 5.8 |
| Molecular Weight | lbs/lb. mole | | 28.5 | 28.7 |
| (3) Gas Flow-Total Windbox | $m^3$/min. | (acfm) | 19,682 (694,971) | 19,682 (694,971) |
| @ Temperature | °C. | (°F.) | 109.4 ( 229) | 105 ( 221) |
| @ Standard Cond. | $Nm^3$/min. | (dscfm) | 13,933 (491,824) | 14,433 (509,501) |
| Moisture | % Weight | | 8.0 | 5.8 |
| Molecular Weight | lbs/lb. mole | | 28.5 | 28.7 |
| (4) Percent Recycle | % | | 26.4 | 0 |
| (5) Particulates (Filterable) | mg/$Nm^3$ | (grs/dscf) | 204 ( 0.0889) | 155 ( 0.0675) |
| | kg/hr. | (lbs/hr. ) | 48.6 ( 107 ) | 39.3 ( 86.5 ) |
| (6) Condensable Hydrocarbons Filter Fraction | mg/$Nm^3$ | (grs./dscf) | 0.78 (0.00034) | 0.92 ( 0.0004) |
| | kg/hr. | (lbs./hr. ) | 0.18 (0.40 ) | 0.23 ( 0.5 ) |
| Back-Half | mg/$Nm^3$ | (grs./dscf) | 2.05 ($8.93 \times 10^{-4}$) | 2.08 ($9.07 \times 10^{-4}$) |
| | kg/hr. | (lbs./hr. ) | 0.49 (1.08 ) | 0.53 (1.16 ) |
| (7) Sulfur Dioxide | mg/$Nm^3$ | (grs./dscf) | 2.78 (0.00121) | 100 (0.0439 ) |
| | kg/hr. | (lbs./hr. ) | 0.64 (1.4 ) | 24.9 (54.8 ) |